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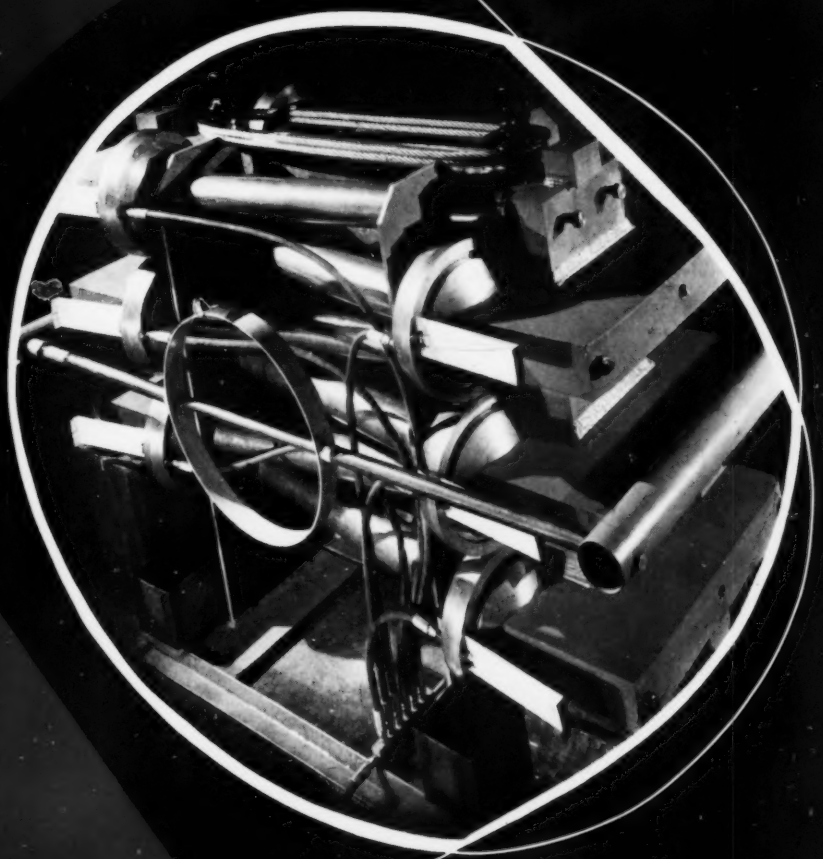

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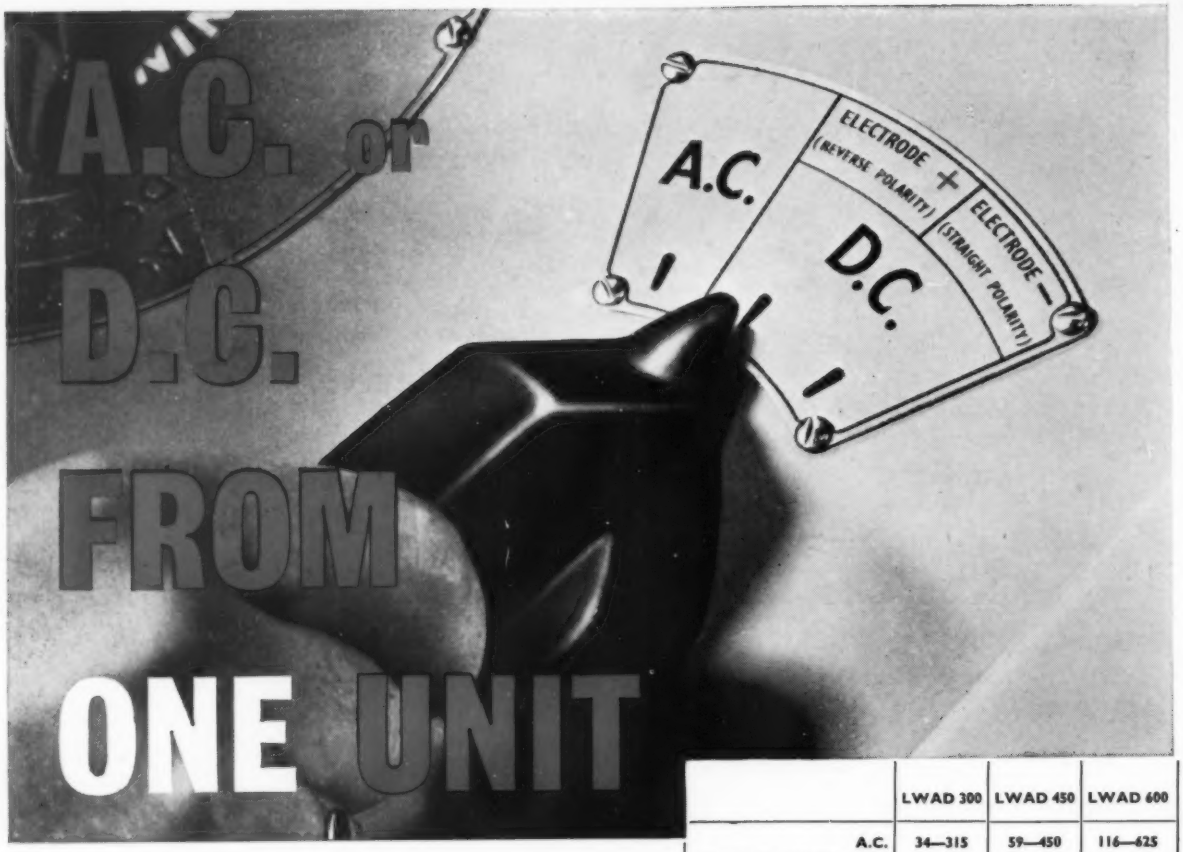

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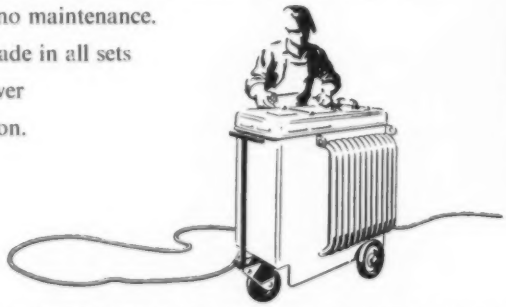

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Inside front cover

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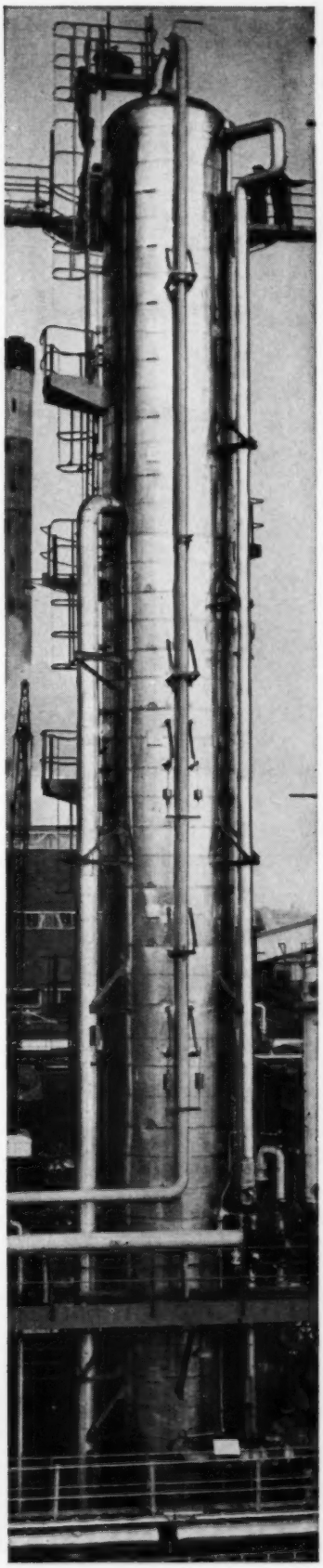

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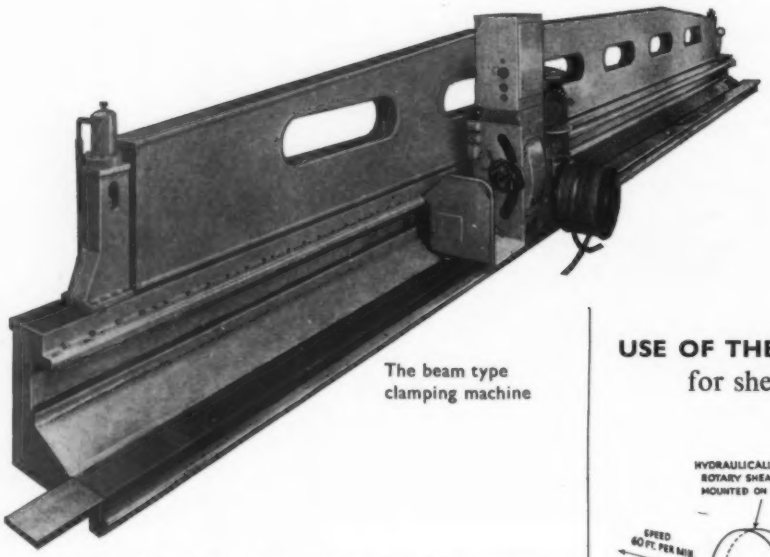

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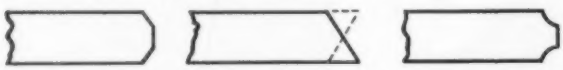

Any welding profile can be provided and in the case of J or double J profiles planing is the only practical method.

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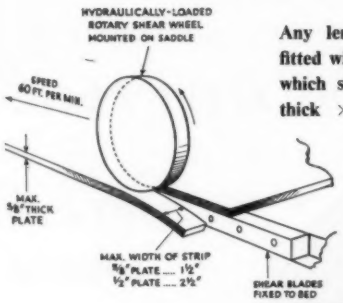
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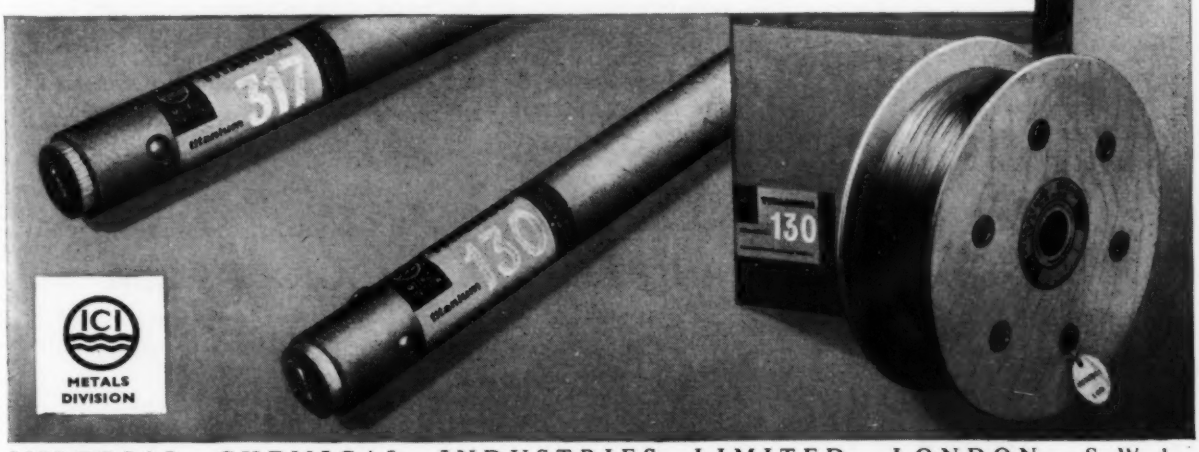

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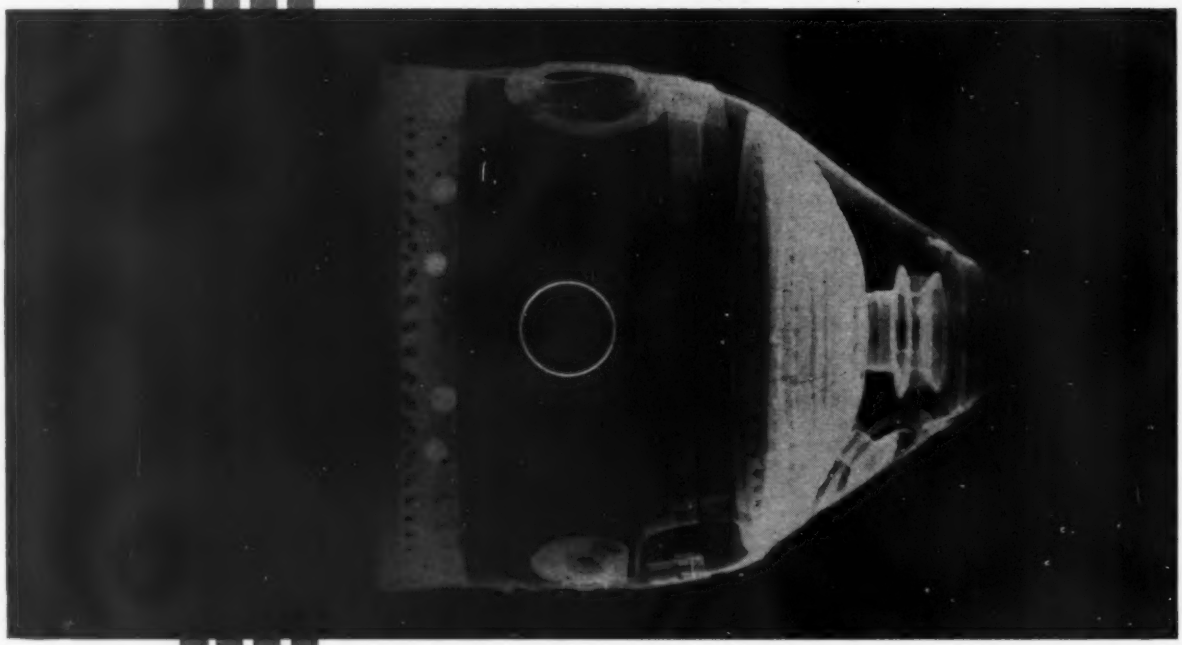

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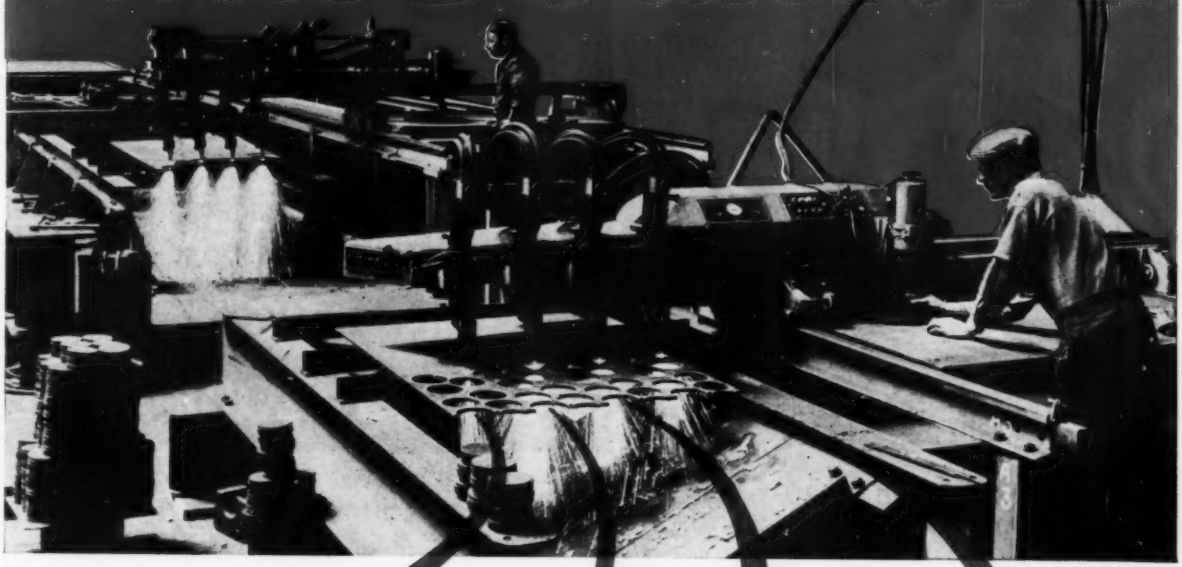

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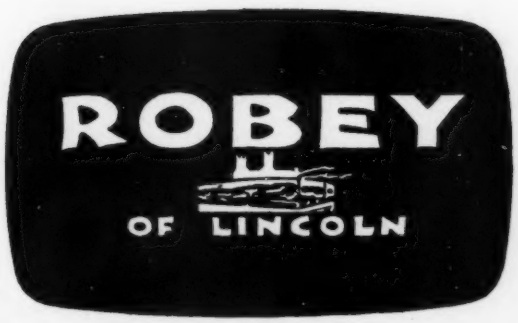

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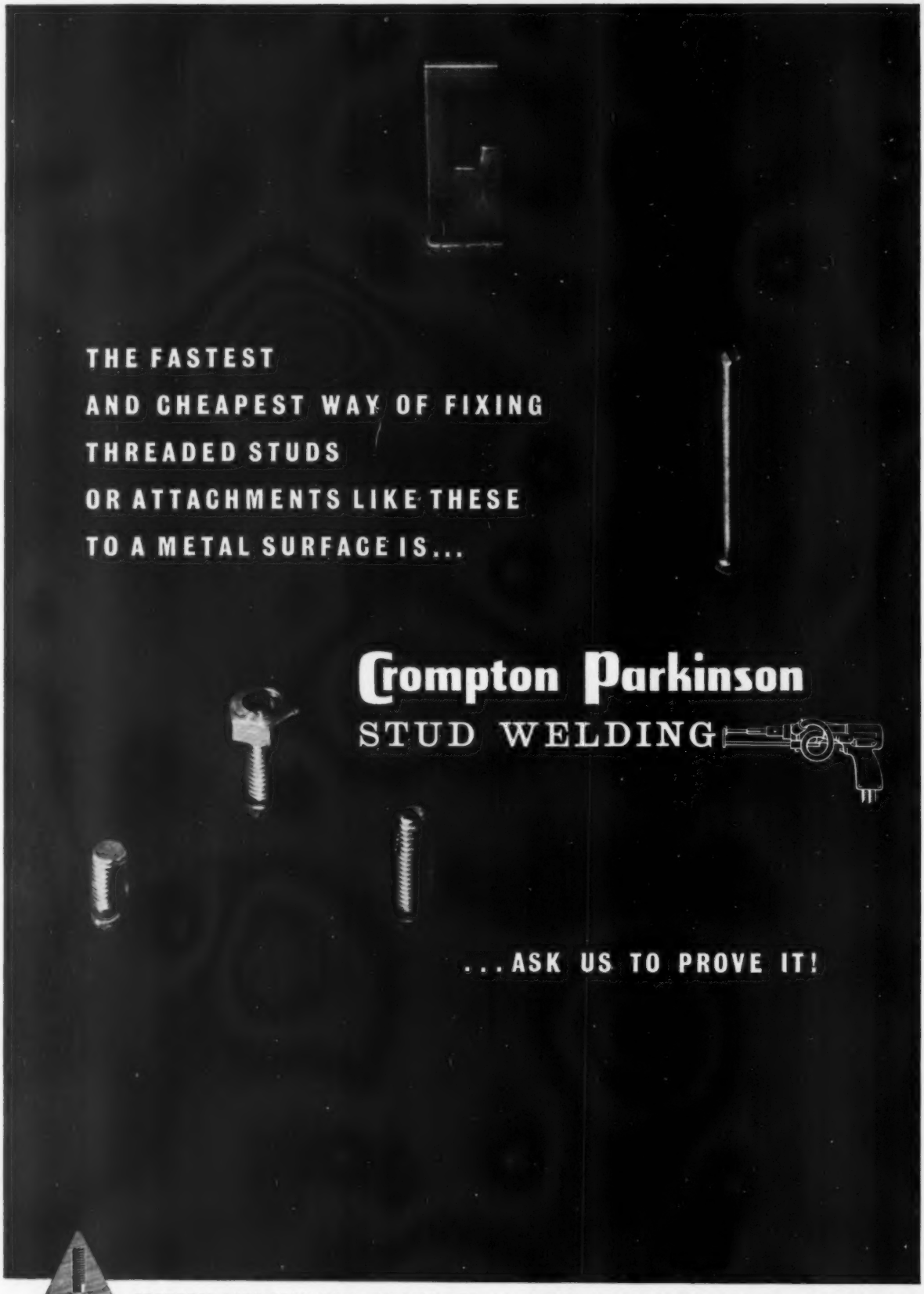
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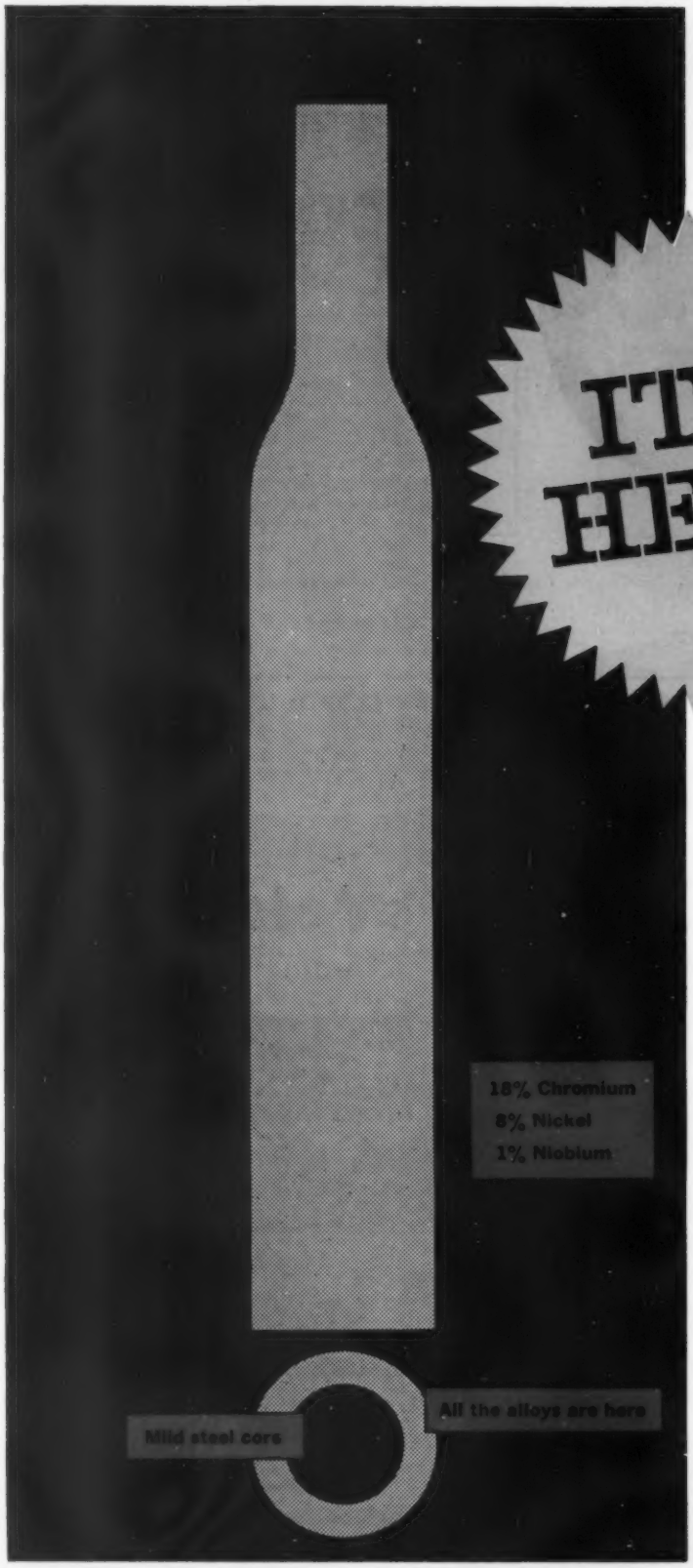

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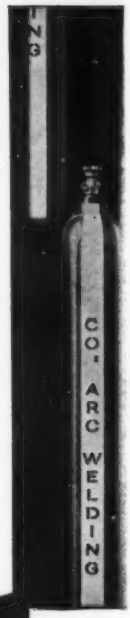

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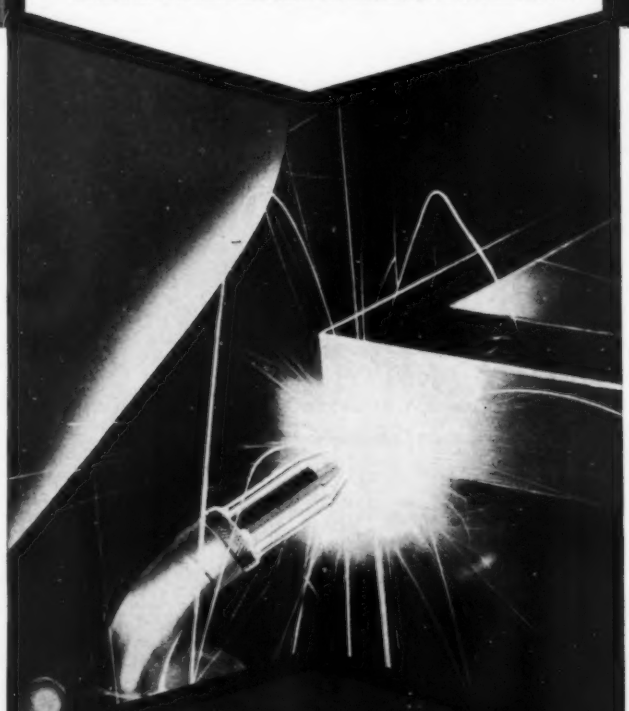

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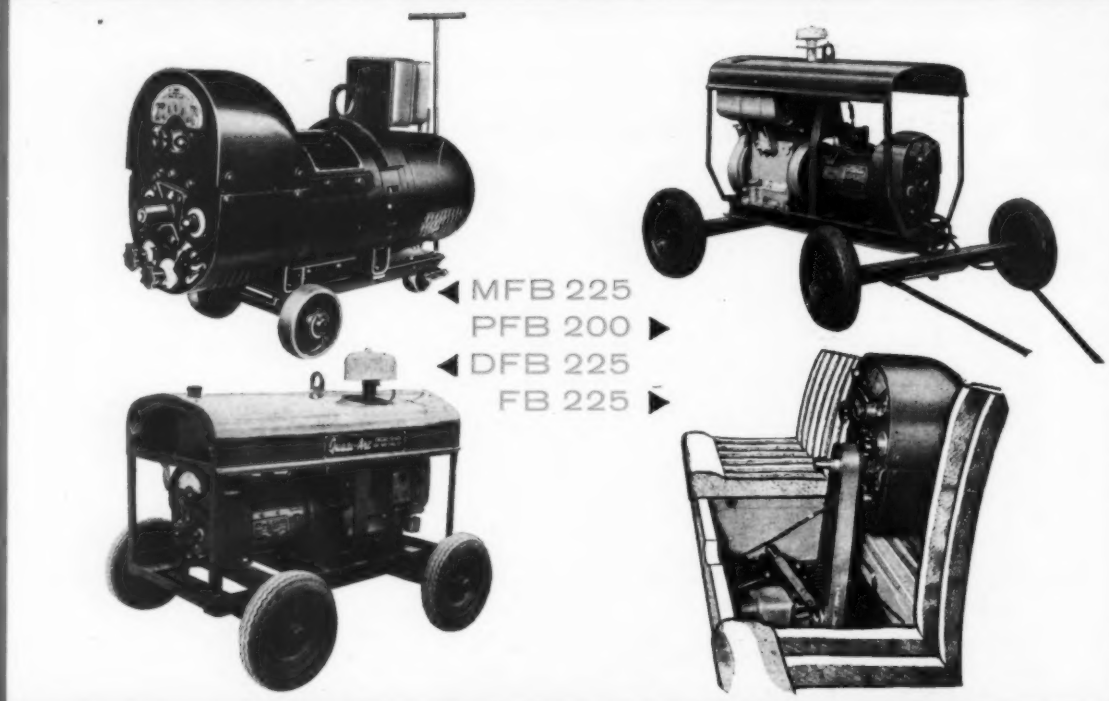

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Welding TECHNOLOGY

Pressure Welding by Rolling at Elevated Temperatures

By M. G. Nicholas and D. R. Milner

The investigation of autogenous pressure welding by rolling, reported in previous papers, has been extended to examine the effect of increasing the temperature of welding for aluminium, Armco iron, magnesium and zinc. The threshold deformation at which bonding first occurs decreases with increasing temperature, and for otherwise similar conditions of welding is related to the homologous temperature, i.e., *the temperature of welding expressed as a proportion of the melting point of the metal concerned.*

The increase in the strength of the weld with increasing degrees of deformation was shown in earlier work to be determined by the fragmentation of the oxide films on the surface to be welded, thus exposing metallic area for potential bonding. A quantitative theory was postulated based on metallographic observations of welds produced at room temperature. The present work has shown that this theory has to be modified for aluminium welded above 200°C., for iron above about 700°C., and for the hexagonal metals, magnesium and zinc, which have poor bonding characteristics.

Introduction

THIS is the third report on an investigation of pressure welding. The first paper[1] dealt with the reasons for choosing roll bonding as the experimental technique, the development of a test which determined the shear strength of the joint, and the results of an investigation of autogenous roll bonding at room temperature. From this work it was clear that the surface preparation of the specimen before welding was one of the most important, but least understood, variables, and the factors involved in surface preparation were therefore further investigated and the results reported in a second paper.[2] The progress which this work has made towards an understanding of the mechanism of roll bonding at room temperature can be summarised as follows.

Welding has been found to occur only at the metallic regions created when the brittle surface layers (oxide films, etc.) fracture as the composite extends in the roll gap. Welding does not take place between oxide-coated surfaces. With composites prepared for welding by scratch-brushing the oxide film forms on a heavily worked layer, which also fractures as the composite is extended, and can be distinguished at the interface by suitable metallographic techniques. Observations on the size and frequency of these particles in joints in aluminium, copper, and iron showed that the scratch-brushed layers were completely brittle and that they came together as the two-ply composite entered the roll gap and then behaved as one layer and broke up as one (*i.e.*, the total length of all the particles at the interface equalled the original length of the composite). The location of the scratch-brushed layers was therefore also that of the surface oxide films.

The maximum area available for welding is thus the increase in area of the interface, which geometrical considerations show to be equal to $R\%$ of the total extended interface, where R is the reduction in thickness of the specimen. When bonded areas are formed they are stronger than would be expected on a simple area basis, owing to the restraint exerted by the surrounding bulk metal upon the ability of the bridge

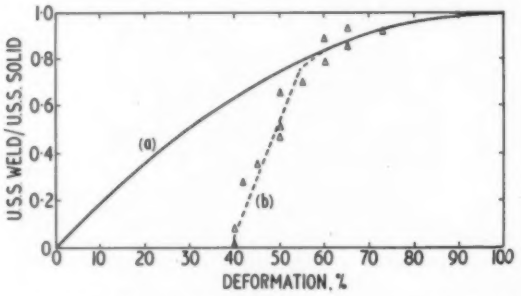
Manuscript received 11th April, 1960.

Mr Milner is in the Department of Industrial Metallurgy of Birmingham University. Dr Nicholas, formerly in the same Dept., is now with the General Telephone and Electronics Laboratories, New York.

material to yield. Experiments with notched bars have shown that there is a simple relation between the U.T.S. and the degree of restraint (neck-area/bar-area); assuming that a similar relationship holds for the ultimate shear strength (U.S.S.) of the welded interface, the strength of a weld between scratch-brushed surfaces, in which all available virgin metal welds up, can be shown to be related to that of solid metal, and the degree of deformation R by:

$$\frac{\text{U.S.S.}_{\text{weld}}}{\text{U.S.S.}_{\text{solid}}} = R(2-R) \quad \ldots\ldots\ldots\ldots \quad (1)$$

This relationship, which represents the maximum attainable strength, is shown by curve (*a*) Fig. 1. In a typical experiment, no bonding occurs below a threshold deformation, after which the bond strength



1—*Variation of strength with deformation for commercial purity aluminium:* (a) *Maximum strength;* (b) *typical experimental result*

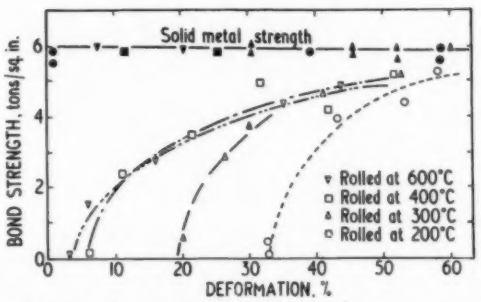
develops rapidly with increasing deformation, attaining and thereafter concurring with the theoretical maximum strength, curve (*b*). Experimental curves of this type were obtained, not only for the work-hardening metals aluminium and copper, but also for tin and lead in which the scratch-brushed layers were ductile and, on rolling, extended along the interface, thus making the location of the oxide fragments impossible to determine. It therefore appears that when the two oxide films on these metals fracture independently of any underlying layer, they still break up as one. No explanation could be advanced for the lack of bonding below the threshold deformation and the partial bonding that occurred at deformations just over the threshold, but it was shown that, in addition to varying from one metal to another, the extent of bonding was related to surface preparation, pressure, time of application of load, and temperature. Only a very limited amount was known of the effect of temperature on bonding, and the present paper is devoted to a more comprehensive investigation of this important practical and fundamental variable.

The available knowledge of the high-temperature pressure-welding characteristics of various metals led to an initial choice of three metals for study: Armco iron and aluminium, representing cubic structure metals which respectively do and do not dissolve their own oxides, and magnesium as an example of a hexagonal metal. However, as it was found that magnesium possessed anomalous welding properties, the investigation was extended to include another hexagonal metal, zinc.

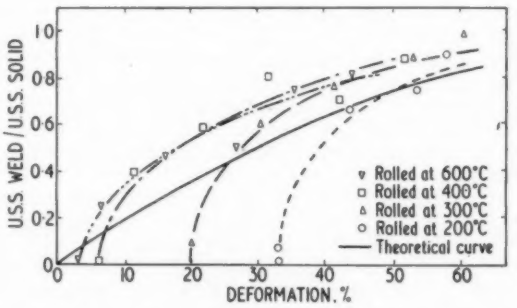
Experimental Technique

The methods of specimen preparation and joint strength determination used in this work were as described in the first paper of this series,[1] except that welding at high temperatures introduced the problem of the development of thick oxide films on the surface of the composite during heating before rolling. To overcome this difficulty the composite was sealed round the edge by one of two methods: with aluminium and zinc an indentation pressure weld was made around the periphery of the composite at room temperature, but owing to the poor room-temperature deformation characteristics of magnesium, and the very high load required to pressure-weld Armco iron, composites of these metals were sealed by fusion welding using the argonarc process in an argon-filled chamber. The size of most of the composites was that shown previously to yield results of general applicability, *i.e.*, $4\times4\times0{\cdot}5$ in., but at one stage of the investigation shortage of magnesium led to the use of tapered composites. These were somewhat larger (9×5 in.), but by tapering them from 0·3 to 0·6 in. at the thicker end, rolling to a uniform thickness, and then dividing them into $\frac{1}{2}$ in. wide test strips by cuts perpendicular to the rolling direction, the variation of the strength over a wide range of deformation could be found from one specimen.

The composites were degreased in trichlorethylene vapour, scratch-brushed, edge welded within a few minutes and then raised to the required temperature by heating for 45 min. After rolling, the composites



2—*Variation of strength with deformation for aluminium welds made at various temperatures*



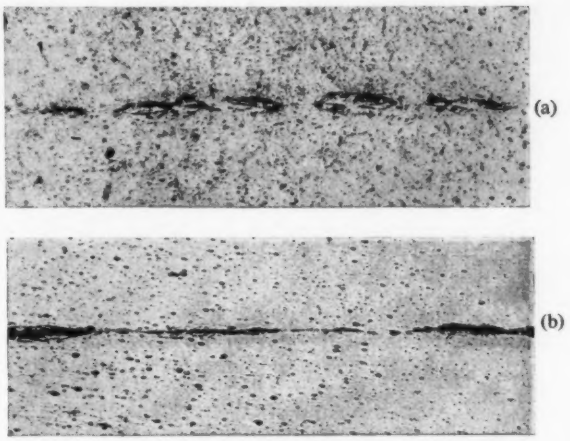
3—*Strengths of aluminium welds (Fig. 2) replotted as proportions of solid-metal strength. Theoretical curve based on* $\text{U.S.S.}_{\text{solid}}$ *of 6 tons/sq.in.*

were air cooled, or quenched when it was necessary to reduce to a minimum any effect of post-annealing. Test specimens $\frac{1}{2}$ in. wide were cut from the composite, and a small area at the cente of the joint was isolated by cuts about $\frac{1}{10}$ in. apart in opposite sides of each member of the composite. The specimen was then pulled in a tensile testing machine to give the shear strength of the joint. The metallographic technique used was an initial rough polish on emery papers with paraffin as a lubricant, followed by diamond dust polishing, except for magnesium which was electrolytically polished to avoid the formation of heavily distorted polishing layers.

Results

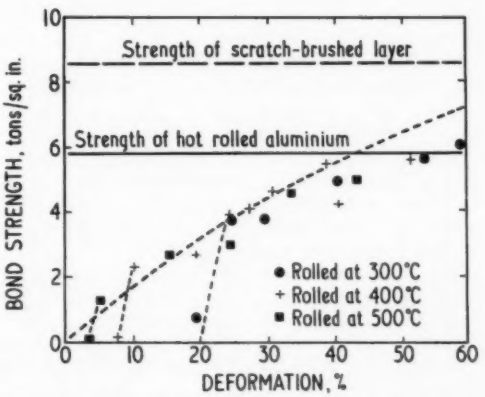
Aluminium

The variation of bond strength with deformation was investigated for aluminium composites welded over the temperature range 200°–600°C. The strengths of solid pieces of metal which had been deformed at the same temperature were also measured, and both sets of results are shown in Fig. 2. The bond-strength/deformation curves had the characteristic shape that had been found for room-temperature welding, but the threshold deformation for bonding decreased markedly as the temperature of rolling was raised until, at 600°C., welding was obtained with only 5% deformation. To test the applicability of the maximum strength theory evolved from the results on room-temperature welding, the weld strengths were re-plotted (Fig. 3) as a proportion of the solid metal strength and compared with the theoretical curve given by equation (1). It can be seen that the bond strengths of composites joined at 200°C. were equal to the proportion of the solid metal strength predicted by the theory, but were higher at more elevated temperatures. The reason for these higher strengths was revealed by metallographic examination of the weld interfaces; whereas at room temperature the scratch brushed layer had been brittle, and fragmented when the composite was rolled (Fig. 4*a*), at temperatures of 300°C. and more the scratch-brushed layer was ductile and extended along the length of the weld interface (Fig. 4*b*). At 200°C. it behaved in an intermediate manner, showing partial fragmentation with some ductility. Thus, whereas at room temperature the oxide film broke up with the underlying scratch-brushed layer and bonding took place between areas of aluminium of approximately the same hardness as the bulk of the metal, at higher temperatures bonding took place between the scratch-brushed layers. It has been shown[1] that this layer was considerably harder and stronger than the adjacent bulk metal; thus the higher strengths could be ascribed to the inherent higher strength of the material forming the areas of bonding. This strength could not be determined directly but was deduced from the hardness of the extended scratch-brushed layers. Owing to the limited thickness of these layers (about 10 microns) conventional hardness determinations could not be made. Instead a micro-indentation technique was used with a 1g load, and the size of the impression was compared with indentations made at a similar load in copper at various states of work-hardening, with the assumption that metals of the same hardness have the same strength. By this method the hardness of the interfacial layer was found to be 66 ±6 D.P.N., corresponding to a shear strength of 8·5 ±0·5 tons/sq.in. (compared with the shear strength of the bulk metal of 6·0 ±0·2 tons/sq.in.). Using this value in equation (1), good correspondence was found between theoretical and experimental results up to 45% deformation, as shown in Fig. 5. Above 45% deformation, the predicted strength of the joint between the scratch-brushed layers was greater than that of the adjacent bulk metal, which therefore determined the failure load.



4—*Welds in aluminium:* (a) *Typical interface produced by rolling at room temperature;* (b) *interface produced by rolling at 300°C. or above* ×100 approx.

Confirmation of the validity of this argument was sought by determining the strengths of welds made between surfaces which had not been scratch-brushed and which would therefore be expected to conform to the bond-strength/deformation relationship based on the shear strength of the bulk metal. It had been shown previously[2] that aluminium could be welded without any surface treatment provided that the contaminant surface layers were first baked off, and that this could be accomplished by heating the specimens in air. A series of tests was therefore made to



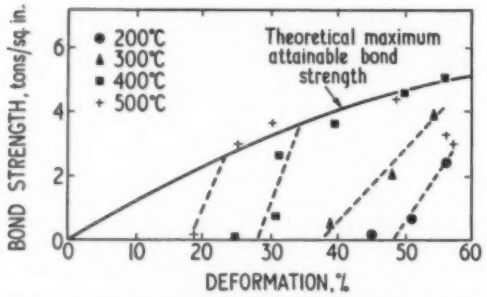
5—*Strengths of aluminium welds (Fig. 2) compared with theoretical curve of strength of scratch-brushed layer*

determine the variation, with deformation and temperature, of the bond strength of composites for which the only preparation had been degreasing followed by heating to the temperature required for rolling (Fig. 6). For temperatures greater than 300°C. the bond strengths agreed reasonably well with the theoretically maximum attainable values; at 300°C. and below the strengths were lower than those predicted, but the earlier work had shown that adequate removal of contaminants was not achieved by heating at these temperatures.[2,3]

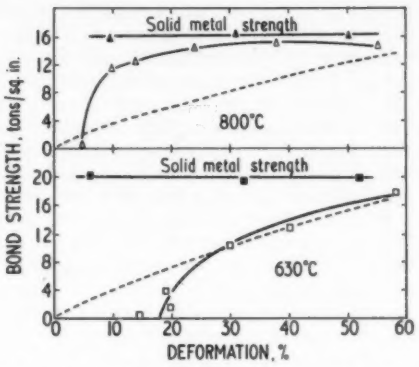
Equation (1) was derived from observations on the interfaces of composites bonded at room temperature, where break-up of the oxide films was determined by that of the underlying scratch-brushed layers, which were completely brittle and fragmented as one during rolling. Since good correlation was obtained between the strengths predicted from equation (1), and the experimental results for welding at temperatures at which the scratch-brushed layer was ductile, and therefore played no part in determining the fragmentation of the oxide films, it would appear that the two oxide films broke up as one in this case also. The results of the investigation of the welding of tin and lead at room temperature led to the same conclusion but, as will be shown later, it is not necessarily valid for all metals.

Armco iron

The pressure-welding characteristics of various irons and steels have been investigated by a number of workers[5–10] and therefore in the present work it was necessary only to obtain sufficient data for correlation of the roll-bonding properties of Armco iron with those of the other metals examined. Firstly, the variation of the bond strength with deformation was determined at the lowest temperature at which heavy reductions could be made with the available rolling mill, *i.e.*, 630°C., and then at 800°C. to determine the effect of increasing the temperature (Fig. 7). The strengths obtained by rolling at 630°C. agreed well with those predicted by the maximum strength model, but for welding at 800°C. they were much higher and approached the strength of solid metal at only 20% deformation. This marked dependence of bond strength on temperature was further emphasised by the results of determination of the variation of bond strength over the temperature range 630°–900°C. at two degrees of deformation—14% and 23% (Fig. 8). (In similar tests with a deformation of 5% no joining was obtained.) The strength increased rapidly with



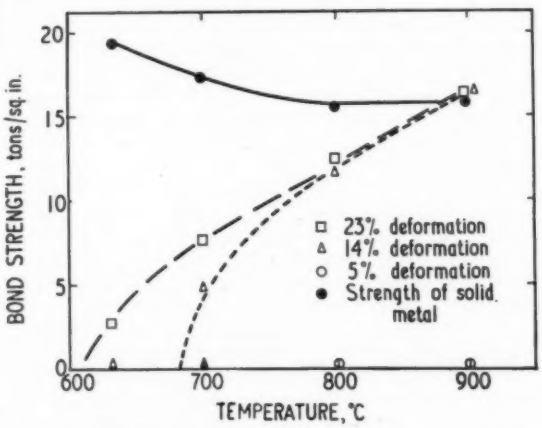
6—*Strength of welds in aluminium, surfaces not scratch-brushed*



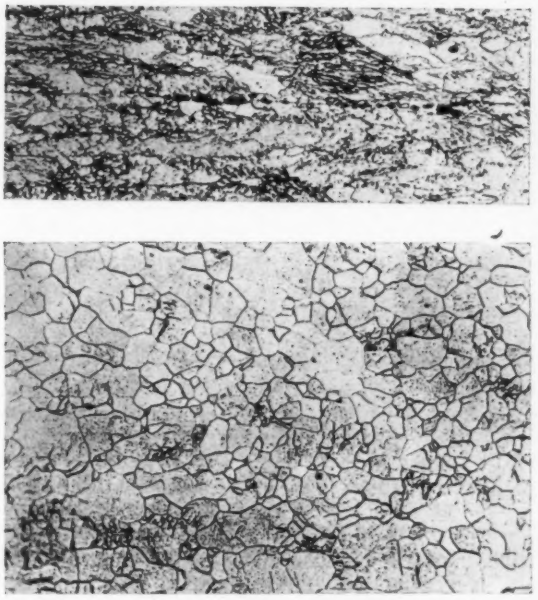
7—*Variation of strength with deformation for welds in Armco iron*

temperature until at 900°C., after having undergone only 14% deformation, it was equal to that of solid metal. Above 800°C. the temperature of rolling was the most important factor, for increasing the deformation by 10% had no effect on the bond strength whereas a 10% increase in the temperature of rolling increased the strength by 4 tons/sq.in., that is, by 30%.

Metallographic examinations of the weld interfaces showed that the high strengths were brought about by the removal of the scratch-brushed layer. This is illustrated by Fig. 9 which shows the effect of increasing the temperature of welding from 700°C., when the interface appeared similar to that in other metals, to 900°C., when the obliteration of the effects of scratch-brushing was complete, and grain growth had occurred across the interface. Further experiments showed that considerable elimination of the scratch-brushed layer took place during the 45 min heating of the specimen before rolling. This can be seen from Fig. 10 in which (*a*) is a photograph of a normal scratch-brushed surface, and (*b*) and (*c*) are scratch-brushed surfaces which have been heated for 45 min in argon at 700° and 900°C., and then quenched. Figure 10*b* shows some signs of surface modification and the partial removal of the oxide film, while Fig. 10*c* shows that the scratch-brushed layer has



8—*Variation of strength with temperature, at constant deformation, of welds in Armco iron*



9—*Welds in Armco iron which had undergone 35% deformation:* (a) *at 700°C.;* (b) *at 900°C.* ×160 approx.

completely recrystallised with marked grain growth and that thermal etching has taken place, sharply delineating the grain boundaries.

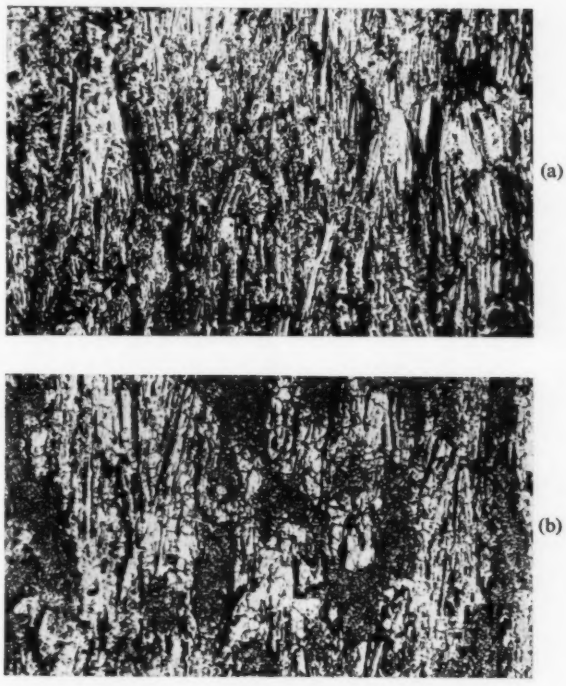
Although the bond strengths predicted by the maximum strength model were exceeded at welding temperatures of 700°C. and above, that part of the theory which relates the strength of the joint with the amount of discontinuity distributed along the interface should still be valid. Thus the strength of the joint should be determinable from the apparent bond area observed on the microstructure according to

$$\frac{\text{U.S.S.}_{\text{weld}}}{\text{U.S.S.}_{\text{solid}}} = B(2-B) \quad \ldots\ldots\ldots\ldots \quad (2)$$

where B is the proportion of the interface which has apparently bonded. To test this hypothesis, the apparently bonded area was measured by scanning weld interfaces at a magnification of about 1000, and comparing the strengths predicted with those determined experimentally. The results, which are presented in Table I, show that the microstructure can be used in this way to give an indication of the strength of the joint.

Magnesium and zinc

Attempts had previously been made to roll-bond magnesium when investigating welding at room temperature,[1] but with deformations up to 50% no bonding was obtained, whilst the ductility of the metal was insufficient to sustain higher deformations without total disintegration. A similar result was obtained when the temperature of rolling was increased up to and including 300°C. However, at 400°C. the metal was ductile and bonding occurred, but with joint strengths considerably lower than the strength of solid metal and a threshold deformation of 35% (Fig. 11),



10—*Scratch-brushed surfaces of Armco iron* (a)*: After scratch-brushing;* (b) *after sealing from atmosphere and heating to 700°C. for 45 min;* (c) *after sealing from atmosphere and heating to 900°C. for 45 min* ×320 approx.

which was considerably higher than that for cubic metals rolled at an equivalent temperature (*i.e.*, the same proportion of the melting point). Increasing the temperature of rolling to 500° and 550°C. brought about a reduction of 10–15% in the threshold deformation, but did not increase the strength of the bonds, whilst rolling at 600°C. proved to be impossible owing to ignition of the composite. No explanation for the low bond-strengths was obtained from a metallographic examination of the weld, which showed that the scratch-brushed layer had extended to form a thin continuous interface with no means of discerning the bonded from the unbonded regions (Figs. 12*a* and *b*).

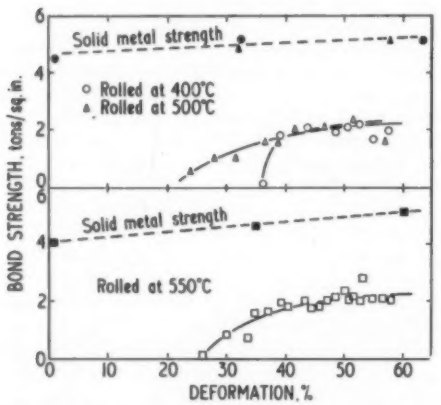
From these experiments it was clear that magnesium had poor bonding characteristics which departed markedly from the behaviour of the other metals examined. To determine whether this occurred with

Table I

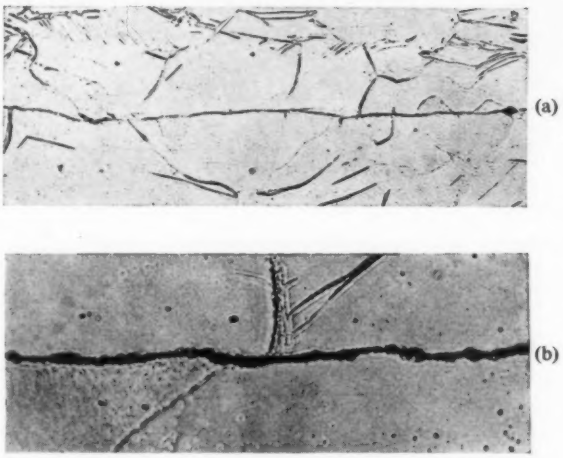
Comparison of experimentally determined strengths of Armco Iron with those calculated from the apparent area of welding

Deformation, %	*Temperature, °C.*	*Proportion of Interface Apparently Bonded*	*Bond Strength as a Proportion of that of Solid Metal Derived from Bond Areas*	*Experimental*
14	630	0	0	0
23	630	0·20	0·36	0·15
14	700	0·25	0·43	0·30
23	700	0·30	0·51	0·45
14	800	0·60	0·84	0·75
23	800	0·65	0·88	0·80
14	900	1·00	1·00	1·00
23	900	1·00	1·00	1·00

other hexagonal metals similar measurements were made of the roll-bonding properties of zinc. A limited investigation had previously been made[1] of the welding of zinc at room temperature, when the threshold deformation was found to be high and the bond strengths exhibited considerable variation. Metallographic examination had also shown the scratch-brushed layer to fragment in some areas, and in other regions to extend so as to form a continuous interface. Further experiments on roll bonding at room temperature confirmed the variation in the bond strengths whose mean values were of the order of half the strength of solid metal (Fig. 13*a*). When welded at higher temperatures (200° and 350°C.) the variation in bond strength diminished, but strengths were consistently low (Fig. 13*b*), having about the same relation ship to the strength of solid metal as that found for magnesium. Metallographic examination confirmed the previous observation that with the room-temperature-welded specimens the scratch-brushed layers behaved respectively in a brittle manner and a partially ductile manner in different regions; this may be associated with the variation in the bond strength, but no correlation was sought to prove this point. Specimens welded at the higher temperature showed the scratch-brushed layers to have extended in a ductile manner, but the structure of the interface could not be resolved.



11—*Variation of strength with deformation for welds in magnesium*



12—*Welds in magnesium:* (a) *General appearance of interface* (×180)*;* (b) *enlarged section of same interface* (×1200)

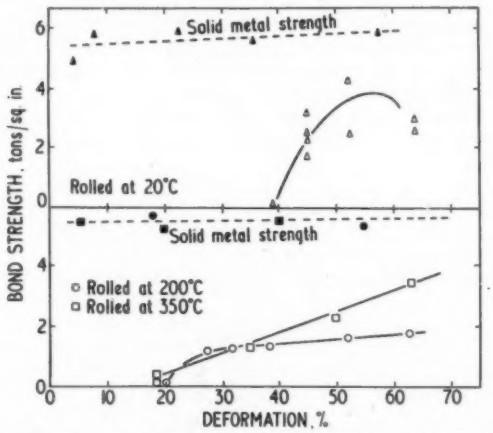
The similarity of the results obtained with magnesium and zinc suggested that there is a difference between the roll-bonding characteristics of the cubic and the hexagonal metals, and that the maximum-strength model did not apply to the hexagonal metals. Accordingly the assumptions implicit in this model were re-examined; the following reasons for the deviation of the hexagonal metals appeared to be possible:

(*a*) The two oxide films did not break up as one when the composite was extended during rolling, so that the region in which virgin metal areas appeared opposite each other was considerably decreased

(*b*) The oxide films broke up in the same manner as with the cubic metals, but the production of the weld was fundamentally more difficult with hexagonal metals

(*c*) The processes of joining occurred in exactly the same manner as with the cubic metals, but when subjected to stressing the strengths of the bonds was not increased to the same extent by the restraint exerted by the adjacent metal.

Of these possibilities the third, *i.e.*, the effect of restraint upon the strength of the metal, was amenable



13—*Variation of strength with deformation for welds in zinc made at various temperatures*

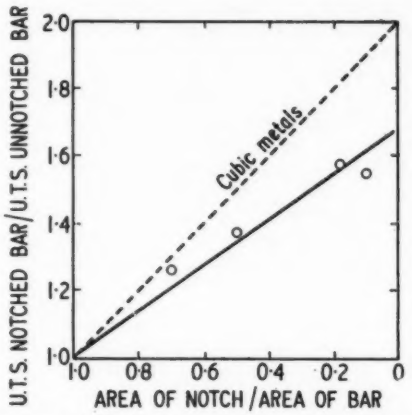
to experimental investigation by the notched-bar method used for the cubic metals. The relationship between the U.T.S. of a neck in a cylindrical notched bar and the degree of constraint (neck-area/adjacent-area of bar) was therefore determined for magnesium. It was found (Fig. 14) that although with the same degree of restraint, lower strengths were obtained than with the cubic metals, the decrease was insufficient to account for the low joint strengths, and only amounted to a change in weld strength from:

$$\frac{\text{U.S.S.}_{\text{weld}}}{\text{U.S.S.}_{\text{solid}}} = R(2-R)$$

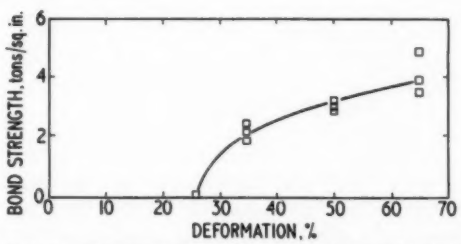
to

$$\frac{\text{U.S.S.}_{\text{weld}}}{\text{U.S.S.}_{\text{solid}}} = R(1{\cdot}7-0{\cdot}7R)$$

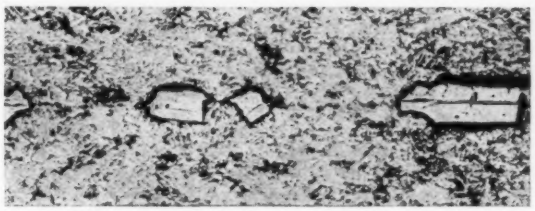
A decision on which of the two remaining hypotheses was the more likely could not be so readily obtained, as it depended on observing the area available for bonding by determining the position of the oxide fragments at the interface. With cubic structure metals it was possible to roll bond at temperatures at which the scratch-brushed layer was brittle, so that the position of the oxide film could be determined from the position of this underlying layer. However, with the hexagonal metals, welding could be obtained only at temperatures at which the scratch-brushed layer extended along the interface. The position of the oxide fragments could not then be determined by normal optical techniques, and another method was therefore adopted. A brittle layer of a copper–5% tin alloy was electro-deposited on the surface of the zinc, and surface



14—*Variation of U.T.S. with restraint of notched bars of magnesium*



15—*Variation of strength with deformation for zinc with electrode deposited layer of 'brittle' copper, rolled at room temperature*



16—*Appearance of interface of copper-coated zinc welds* ×85 approx.

contaminants (other than the oxide film) were baked off by heating to 350°C. for 45 min before welding. The bond strengths obtained with composites thus treated and rolled at 300°C. were then correlated with the joint area determined from microscopical observation of the weld interface. Figure 15 shows that bond strengths were somewhat higher than those obtained with a scratch-brushed surface that deformed in a ductile manner on rolling (*see* Fig. 13). In addition, the micrograph in Fig. 16 and the data in Table II showed that, while the area available for bonding approached the increase in area of the interface, it was somewhat less owing to a tendency for parts of the copper layer to twist and thus increase the area over which bonding was inhibited. But the most significant result was that the strength, calculated on the assumption of complete joining of the areas between the fragmented layer, agreed well with the experimentally determined bond strengths. This showed that there was no fundamental difficulty in achieving bonding across an interface with hexagonal metals, and thus disposed of hypothesis (2), leaving only the possibility that the two oxide films did not break up as one.

Since the position of the oxide fragments was not observable, the only test that could be made of this hypothesis was a comparison of the bond strengths with those predicted theoretically on the assumption of the two oxide films breaking up independently. If the oxide films are brittle, and thus occupy an area at the interface equivalent to the original area of the composite, the proportion of the surface of one composite that is virgin metal potentially available for bonding is equal to the reduction R. Since this is the same for each member of the composite, the proportion of the interface at which virgin metal areas are formed opposite each other is R^2. Figure 14 showed that for magnesium the strength under restraint could be represented approximately by:

$$1{\cdot}7-0{\cdot}7\times\frac{\text{area of joint}}{\text{area of adjacent metal}}$$

and as the latter term is equal to R^2, the strength of a weld in magnesium in which the two oxide films break up independently is given by:

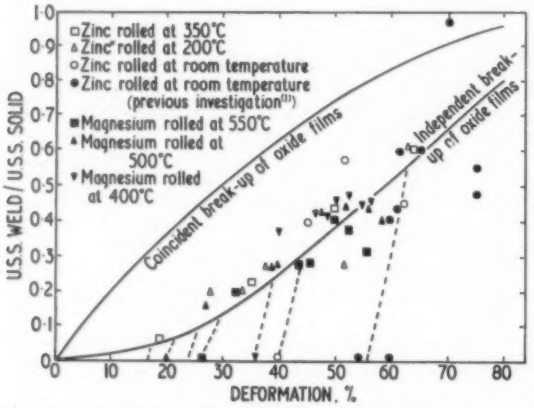
$$\frac{\text{U.S.S.}_{\text{weld}}}{\text{U.S.S.}_{\text{solid}}} = R^2\,(1{\cdot}7-0{\cdot}7R^2)$$

This theoretical relationship is compared with the experimental results for magnesium and zinc in Fig. 17; this shows that the hypothesis of independent break-up of the two oxide films agrees far better with the observed results than does the theoretical relationship

Table II

Comparison of the experimentally determined strengths of copper plated magnesium welds with those calculated from the apparent area of bonding

Deformation, %	*Proportion of Interface Apparently Bonded*	*Bond Strength as a Proportion of that of Solid Metal*	
		Derived from Bond Areas	*Range of Experimental Values*
26	0	0	0
35	22	0·39	0·36–0·44
50	38	0·63	0·51–0·58
65	60	0·84	0·65–0·93


Zinc rolled at 350°C
Zinc rolled at 200°C
Zinc rolled at room temperature
Zinc rolled at room temperature (previous investigation[11])
Magnesium rolled at 550°C
Magnesium rolled at 500°C
Magnesium rolled at 400°C
Coincident break-up of oxide films
Independent break-up of oxide films
U.S.S. WELD / U.S.S. SOLID
DEFORMATION, %

17—*Strengths of magnesium welds (Figs. 11 and 13) replotted as proportion of solid-metal strength*

derived on the assumption of the two oxide films breaking up as one.

Discussion

The aim of the researches, of which the work presented in this paper forms part, is the elucidation of the mechanism of pressure welding, using roll bonding as the most suitable investigational technique. The work described in previous papers laid the foundations of the approach to this problem and showed how oxide films, present on the surface of metal welded at room temperature, fragmented and exposured metallic areas for potential bonding. The maximum strength that the weld could attain was then related to the amount of metallic area exposed and the strength of the joints. The mechanism of joining of the metallic areas remained unexplained, although it was shown that bonding was determined by a variety of factors. The present work has extended the researches to include the effect of increasing the temperature of welding, and has shown that the maximum strength model must be modified:

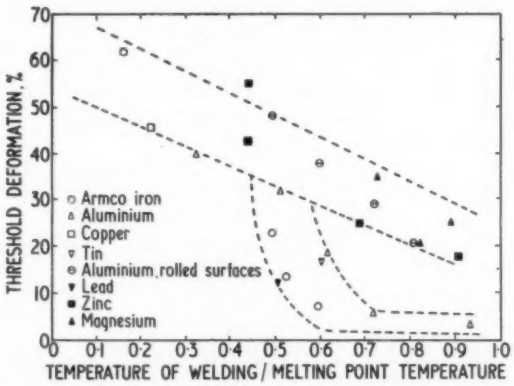
(*a*) For aluminium welded above 200°C., because the scratch-brushed layer becomes ductile and on rolling extends along the interface, so that the bonds are formed between high-strength fine-grained surfaces.

(*b*) With iron above about 700°C., because the scratch-brushed layer recrystallises and the oxide film dissolves into the adjacent metal, thereby increasing the area of welding.

(*c*) For the hexagonal metals magnesium and zinc, which have poor bonding properties, because the two oxide films on the joining surfaces break up independently.

The first two of these phenomena are explicable in terms of accepted concepts, but the factors that govern the fragmentation of the oxide films are not so obvious and require further consideration. As the two members of the composite enter the roll gap the surfaces to be welded will come together and, unless there is a force tending to move them relative to each other, they will stay together, and the two oxide films will break up as one. If the oxide films are to break up independently, then forces must be present which cause the surfaces to move relative to each other. It is difficult to imagine how such forces could arise if the metal were completely homogeneous (like plasticine for example), but when viewed at a microscopic level the ability of a metal to deform varies from point to point. Thus two regions opposite each other in the two members of the composite may not have the same deformation properties, and this will give rise to a force tending to move them relative to each other. Owing to the limited number of slip mechanisms, hexagonal metals inherently possess more inhomogeneity in this respect than cubic metals, so there is a plausible physical basis for the hypothesis that the low bond-strengths observed with hexagonal metals is due to independent break up of the oxide films.

The other aspect of this work which requires discussion is the effect of increasing the temperature of welding on the initiation and development of bonding. It is not proposed in this paper to consider the mechanism of bonding in detail, as work on this problem is continuing and it is hoped to make a positive contribution in a future publication. However, collation of the results that have been obtained so far leads to a useful generalisation. The threshold deformation can be regarded loosely as a measure of the ease of bonding, and since most theories of bonding involve some form of atomic rearrangement it is reasonable that the threshold deformation should decrease with increasing temperature, and hence increasing atomic mobility, in the manner that has been observed. Since the atomic mobility is related to the reduced temperature (*i.e.*, the ratio of the temperature under consideration



18—*Values of threshold deformation of various metals related to reduced temperature. Except for aluminium values are for scratch-brushed composites*

to the melting temperature T_m), rather than to the actual temperature, the threshold deformations that have been reported for seven metals in this and previous papers were plotted against the reduced temperature to give the results shown in Fig. 18.

The threshold deformation appeared to decrease in a similar manner for all the metals examined until a reduced temperature of about $0{\cdot}5T_m$ had been attained. Thereafter the threshold deformation for cubic metals that had been scratch-brushed before welding decreased very rapidly with temperature. At the same temperature the scratch-brushed layer changed from brittle to ductile behaviour on rolling, so that whereas bonds produced below $0{\cdot}5T_m$ were formed between material of normal grain-size which had been forced into the gaps between the fragmented scratch-brushed layer, those made above $0{\cdot}5T_m$ were formed between the fine-grained material constituting the layer. Thus it can be concluded that a very fine grain-size aids bonding, possibly by enhancing diffusion processes through the increased grain-boundary area.

The hexagonal metals do not fit this pattern, since scratch-brushing did not bring about the same reduction in the threshold deformation at $0{\cdot}5T_m$. This may be connected with the small amount of metal-to-metal contact available for bonding, resulting from the independent break up of the oxide films, but it is interesting to note that it has been reported that hexagonal metal powders have poor compacting and sintering properties,[11] and low coefficients of friction[12] (*see* Table III), both of which are related to the ability of the metal to form solid-phase bonds.

If the marked effect of scratch-brushing on welding above $0{\cdot}5T_m$ can be regarded as a separate issue, then increasing the temperature of welding reduces the threshold deformation from about 60–70% at $T_m 0{\cdot}1$ to 30% at $0{\cdot}9T_m$. This is not a vast change considering the temperature range involved, and cannot be compared, for example, with the effect of surface preparation. In this connection it is necessary to add a comment with regard to the use of Fig. 18 as a guide to pressure welding practice. Although the threshold deformation is a simple practical concept, in principle it is a very complicated parameter and is dependent on many variables. The values given in Fig. 18 show relative changes for a fixed technique of bonding, and could be expected to be altered by many factors, *e.g.*, surface preparation, roll speed, time of exposure of the surfaces before welding, metal purity, etc. However, the figure gives an indication of the value of the threshold deformation that can be expected in good pressure-welding practice using simple conventional techniques.

Conclusions

(1) The increase of the strength of the weld with increasing degrees of deformation was shown in earlier work to be determined by the fragmentation of the oxide films on the surfaces to be welded, thus exposing metallic areas for potential bonding. A quantitative theory was postulated based on the metallographic observation of welds produced at room temperature. The present work has shown that this theory has to be modified:

Table III

Coefficients of friction for various metals

Metal	*Coefficient of Friction*
Copper	1·3
Aluminium	1·3
Iron	1·0
Lead	1·5
Magnesium	0·5

(i) For aluminium welded above 200°C., because the scratch-brushed layer becomes ductile and on rolling extends along the interface so that the bonds are formed between a high-strength fine-grained material

(ii) With iron above about 700°C., because the inhibiting surface oxide film dissolves into the adjacent metal, thus increasing the area of welding

(iii) For the hexagonal metals magnesium and zinc, which have poor bonding characteristics, probably because the two oxide films on the joining surfaces break up independently and thus decrease the area over which bonding can occur.

(2) The threshold deformation at which bonding first occurs decreases with increasing temperature, and for otherwise similar conditions of welding is related to the reduced temperature, *i.e.*, the temperature of welding expressed as a proportion of the melting point T_m of the metal concerned. Above about $0{\cdot}5T_m$ the curve has two branches; one branch corresponds to enhanced welding and relates to cubic metals which have been scratch-brushed before welding, whereas the second branch relates to non-scratch-brushed surfaces and to hexagonal metals which have poorer welding characteristics.

Acknowledgments

This work is part of a programme of research into some aspects of the joining of metals which is being carried out at the Department of Industrial Metallurgy at the University of Birmingham. The authors wish to thank Professor E. C. Rollason, Head of the Department, for his interest and encouragement throughout the course of the work, and the Director of the Atomic Energy Establishment for the financial sponsorship of the research.

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REPORT OF COUNCIL FOR 1960

The Thirty-eighth Annual Report of the Council on the activities of the Institute during the twelve months ended 31st March, 1961, was submitted for the approval of members at the Annual General Meeting on Thursday, 13th July, 1961. 660

ANNUAL REPORT

Honorary Officers and Council

The Honorary Officers and Council elected in 1960 took office after the Annual General Meeting on 14th July, 1960. Mr. Edgar Fuchs delivered his Presidential Address to members at the opening of the Autumn Meeting in London on 1st November, 1960 on the subject of "*Quality in Welding*". The address was printed in the *British Welding Journal* for January 1961.

The retiring President, Mr. E. Seymour-Semper, presented a gilt sunray clock to the Institute, which was accepted with the thanks of the Council by the new President in July 1960 and installed in the Council Room.

Advanced Education in Welding

In June 1960, shortly before vacating the Presidency, Mr. Seymour-Semper convened a select Conference on Education in Welding Technology, to which leading representatives of Industry, the Universities and Technical Colleges and the Ministry of Education were invited. A number of papers were read and discussed and the Ministry of Education announced its willingness to consider the establishment of a post-graduate full-time course in Welding Technology, if evidence were forthcoming that such a course would be adequatly supported by Industry. Immediately after the Conference, the British Ogygen Company Limited offered to provide funds for seven years, sufficient to enable the Institute to award two bursaries a year for students attending the proposed post-graduate course. By the end of August promises from A.E.I. Limited and Whessoe Limited to send members of their staff to the course had ensured the necessary minimum number of students, and the Ministry decided to establish the course at the College of Aeronautics, Cranfield, Bedfordshire, to open in the Autumn of 1961. The President set up a special committee to co-operate with the Ministry and with the College in the planning of the course, the prospectuses for which were distributed to member companies of the Institute and of the B.W.R.A. early in 1961, with a letter signed by the Presidents of both bodies, commending the course to the support of the Engineering Industries.

Thus during the year the Institute's long-standing efforts to persuade the educational authorities and the engineering industries of the need for advanced education in Welding Technology were crowned with success. The Council's energies were largely directed to ensuring an adequate flow of students into the course during its first few years and to exploring through a reconstituted Education Committee the implications of this development for other levels of technical education. Some account of the Education Committee's work is given below.

Meetings

The Spring Meeting of 1960 was held at Droitwich from 9th to 11th May. Eleven papers on novel welding processes and on metal spraying were presented and discussed at three technical sessions. As usual there was a choice of works visits on one afternoon and throughout the meeting a small exhibition was mounted in the Winter Gardens. The attendance at this Spring Meeting was the largest in recent years and proved the wide-spread interest in novel developments among the welding and allied processes.

On 6th October members of the Russian Welding Mission which had been visiting this country under the auspices of the welding sections of BEAMA were received at the Institute, where Dr. Paton, their leader, delivered an interesting address and a film of the Russian welding process electro-slag welding was shown. The visitors were afterwards entertained at dinner by members of the Council and others.

A feature of the Autumn Meeting, held as usual in London from 1st to 3rd November, 1960, was the presentation of a report on welding research and practice in the U.S.S.R. by members of the Institute who, with Dr. Weck and other members of the B.W.R.A. staff, had visited the U.S.S.R. during September. This subject was also illustrated by means of a film.

The general theme of the Autumn Meeting was the metallurgy of welding and brazing, ten papers being presented and discussed at two technical sessions, while an evening meeting, held jointly with the Institution of Metallurgists, discussed the rôle of the metallurgist in fabrication involving welding. The attendance at the technical meetings was again very satisfactory but there was a decline in the number attending the annual dinner at the Park Lane Hotel on 3rd November, when the principal guest and speaker was The Hon. Mr. Justice Lloyd Jones.

A novelty of the year was the first Institute Conference on Welding Standardization, held at the Institute on Wednesday, 7th December. A full programme had been arranged and the attendance was encouraging both at the morning and afternoon meetings, but again a little disappointing at the dinner in the evening.

Professor J. G. Ball delivered the second Christmas Lecture to young people on 5th January, 1961; attendance was about the same as in 1960. The Lecturer held the excited attention of eighty or ninety young folk of both sexes throughout his talk on *Sticking Things Together*, which was well illustrated by demonstrations.

A crowded evening meeting on 8th February was privileged to hear Mr. Gilbert Roberts, Senior Vice-President of the Institute, deliver a paper on *The Welded Maidenhead Bridge*, beautifully illustrated with colour transparencies. The Chairman was Mr. H. C. Adams, Assistant Chief Engineer (Bridges) of the Ministry of Transport.

Publications

Substantial progress was made with the enlargement of the *British Welding Journal*, the 1960 volume being 25% above the standard size. Even so it has been difficult to accommodate without undue delay the increasing number of papers which the Institute would like to make available to its members, and a further enlargement was

A list of the Honorary Officers and Council for 1960–1 appears on p. 13 of this issue (Advert Section).

effected at the end of the year by the publication in March 1961 of the first quarterly supplement *International Welding*, containing reports and documents issued by the International Institute of Welding. This supplement is being reprinted for separate circulation, particularly abroad, to those members of the International Institute which take its publications in the English version.

At the end of 1960, the Council was able to issue free to corporate members a printed list of members, together with the Memorandum of Association, Articles of Association, By-Laws and Standing Orders. It is intended that this should be an annual publication in future.

On behalf of the International Institute of Welding the Institute published *Recommended Welding Connections for Pressure Vessels* and *Comparison of Brittle Fracture Tests*. At the end of the year it was about to issue an English edition of the *Handbook on Radiographic Apparatus and Techniques*.

The second and final volume of the *Handbook for Welding Design* was complete and in the hands of the editor by the beginning of 1961, so that publication in 1961–2 may be confidently expected. At the same time a start has been made on the revision of Volume I, the stock of which is now very low, so that a reprint will be needed before long. With these two volumes the book, originally planned in three volumes, will be complete, but it is intended from time to time to publish smaller supplements dealing with the application of the design principles set out in Volume I to welded constructions of different types. Arrangements have already been made for the writing of the first of these supplements dealing with the design of welded ships.

Other publications in preparation were a booklet on Site Welding, which was finished before the end of March, a handbook on Inert Gas Arc Welding, a revised edition of the Health and Safety booklet, and a revised version of the *List of Welding Specifications and Codes*.

Education Committee

In order to concentrate the Institute's work in education, the Education Committee was reconstituted with three Sub-committees: one in charge of the School of Welding Technology, one, entitled the Technical Colleges Sub-committee, to organise co-operation between the Institute and the Technical Colleges, and an Examinations Sub-committee to supervise the Associate-Membership examination.

The main Education Committee is particularly concerned with the formulation of educational policy. The Technical Colleges Sub-committee has been engaged in assisting the growing number of Technical Colleges which ask the help of the Institute in organising welding courses suitable for technicians and is devoting continuous attention to welding education at this level, the most obvious gap remaining in the national system of technical education now that advanced instruction suitable for welding technologists is to be provided at Cranfield.

The scheme and syllabuses for the Associate Membership examination have remained substantially unchanged since they were first drawn up in 1947 and the Examinations Sub-committee has therefore been reviewing and revising these, to take account not only of developing ideas about the rôle of welding engineers in industry but also of the improved facilities for instruction in welding technology now available.

School of Welding Technology

The day and evening courses offered by the School have continued to be well supported by industry. During the year, fifteen full-time day courses were attended by 586 students and the attendance at three evening courses was 329. These courses, in which lectures were given by more than 200 members and other specialists, made available a great store of technical knowledge and experience. The School is a venture in co-operative technical education on a scale probably unsurpassed anywhere in the world and is something of which all members may feel justly proud.

The following is a list of courses held, with attendances:

Day Courses

D 8/2	Welded Structures	27
D 7/2	Ultrasonic Inspection	25
D 9/2	Health and Safety in Welding	32
D 23/1	Training and Testing of Welders	22
D 1/3	Welded Pressure Vessels	50
D 13/2	Residual Stresses and Stress Relief	45
D 12/2	Practical Control of Distortion	53
D 18/1	Metal Spraying	43
D 29	Welding Course for Supervisory Staff	43
D 3/2	Design for Welding in General Engineering	41
D 15/2	Brazing Technology and Design	37
D 32	Design for Welding in Thermoplastics	37
D 5/3	Non-destructive Weld Examination	48
D 22	Welding of Atomic Energy Plant	46
D 4/2	Resistance Welding Technology and Design	37
		586

Average: 39 per course

Evening Courses

E 3 (London)	Design for Welding in General Engineering	111
E 1/8 (Birmingham)	Detail Design of Welded Structural Steelwork	80
E 2/1 (Manchester)	Design for Welding in Heavy Engineering	138
		329

Average: 110 per course

The School Sub-committee has drawn up a provisional programme for the three years up to March 1964; many new courses feature in this programme including a number at advanced level intended primarily for those who have previously attended the standard courses. A number of Advisory Groups are being established to advise the staff on the syllabuses of new and advanced courses.

Awards

The Sir William J. Larke Medal of 1960 was awarded to Dr. L. R. Vaidyanath and Mr. D. R. Milner for their paper on "*Significance of Surface Preparation in Cold Pressure Welding*" published in the January 1960 issue of the *British Welding Journal*.

The paper "*Quelques remarques à propos de la qualité d'image radiographique*" by G. d'Herbemont, contributed to the Joint Meeting with the Société des Ingénieurs Soudeurs in November 1959 and published in summary form in the October 1959 issue of the *British Welding Journal*, was highly commended.

The Tibbenham Prizes, awarded on the results of the City and Guilds of London Institute Welding Examinations of 1960, were won by S. A. Dye (1st Prize) and R. A. Collins (2nd Prize).

Technical Committees

During the year, the Technical Committee has reorganised the framework of sub-committees and panels that it has maintained during the past six years. The new scheme of organisation involves, in principle, the replacement of the majority of the standing sub-committees by Reporting Groups and the transfer of responsibility for special projects and for briefing of United Kingdom delegates to the International Institute of Welding to *ad hoc* committees and Briefing Groups respectively. The Committee believes that the new arrangements will result in a freer flow of technical knowledge into the Institute and a speedier distribution of it to members and industry.

THE INSTITUTE OF WELDING

BALANCE SHEET, 31st MARCH, 1961

31.3.60 £		£ s. d.	£ s. d.
	Accumulated Fund—		
	Balance as at 31st March, 1960	27,041 4 3	
	Add Transfer from Mortgage Redemption Sinking Fund	2,021 3 8	
		29,062 7 11	
	Add Excess of Income over Expenditure for the year	295 5 2	
27,341			29,357 13 1
	Reserve for future Development—School of Welding Technology		850 0 0
	Provisions and Current Liabilities—		
00	Provision for Premises Repairs and Renewals	600 0 0	
00	Reserve for Publications	600 0 0	
153	Overdraft at Bankers (Secured by a charge on Investments)	10,158 8 8	
924	Sundry Creditors and Credit Balances ..	5,852 19 7	
85	Subscriptions, Entrance and Examination Fees received in advance	329 1 0	
13,662			17,540 9 3
	Loan on Mortgage (Secured by a charge on Freehold Property)		
	Balance as at 31st March, 1960	2,000 0 0	
	Less Amount repaid during year	2,000 0 0	
2,000			—
	British Welding Journal—		
54	Subscriptions in Advance		3,265 17 10
	School of Welding Technology—		
555	Fees and Deposits in Advance		514 17 2
	Appeal Funds—		
	"Services to Industry" Fund		
	Balance as at 31st March, 1960 ..	7,037 6 8	
	Add Income for the year to 31st March, 1961	511 18 3	
		7,549 4 11	
	Less Expenditure on replacements and alterations to premises during the year	528 9 7	
7,037			7,020 15 4
	"Furnishing and Equipment Fund"		
	Balance as at 31st March, 1960 ..	24 1 11	
	Add Income for the year to 31st March, 1961	411 15 2	
		435 17 1	
24	*Less* Cost of special furnishings and fittings purchased during the year..	367 14 4	
7,061			68 2 9
	Special Funds—		
90	Sir William Larke Medal Fund	87 6 3	
272	C. W. Hill Prize Fund	284 5 2	
119	Tibbenham Trust Fund	123 13 4	
326	Life Membership Subscription Fund ..	317 2 0	
	Mortgage Redemption Sinking Fund—		
	Balance as at 31st March, 1960 .. .. £1,996 9 0		
	Add Income for Year to 31st March 1961—		
	Interest on Investments 24 14 8		
	2,021 3 8		
	Less Transfer to Accumulated Fund 2,021 3 8		
1,996		—	
2,803			812 6 9
£57,076			£59,430 2 2

31.3.60 £		£ s. d.	£ s. d.
	Fixed Assets—		
	Freehold Property, 54 Princes Gate, S.W.7, at Cost	40,090 13 7	
	Less Depreciation written off	2,100 0 0	
38,691			37,990 13 7
	Note. An amount of £2,275 6*s* 10*d* has been expended on replacements and alterations to premises which has been provided out of the "Services to Industry" Fund as Follows: Year to 31.3.60 £1,746 17*s* 3*d* Year to 31.3.61 £528 9*s* 7*d*		
	Furniture and Fittings at Cost *less* Sales ..	4,935 6 7	
	Less Depreciation written off to date ..	1,792 7 9	
2,770			3,142 18 10
	Council Room Furniture at Cost	409 4 6	
	Less Donations received	363 18 3	
45			45 6 3
	Special Furniture and Fittings at Cost ..	1,987 17 3	
	Less Amount provided out of Furnishing and Mortgage Redemption Fund ..	1,987 17 3	
—			—
41,506			41,178 18 8
	Current Assets—		
490	Stock of Publications	1,163 17 2	
	Investments in Government Securities at Cost (Market Value 31st March, 1961,		
6,222	£5,893)	7,045 11 3	
5,157	Sundry Debtors and Payments in Advance	7,141 15 7	
393	Expenditure on Handbook for Welding Design—*less* Contribution and Sales ..	446 10 1	
	Cash at Bankers and in Hand, Head Office		
505	and Branches	1,641 2 8	
12,767			17,438 16 9
	Special Funds (*Investments and Cash at Bankers*)—		
90	Sir William Larke Medal Fund	87 6 3	
272	C. W. Hill Prize Fund	284 5 2	
119	Tibbenham Trust Fund	123 13 4	
326	Life Membership Subscription Fund ..	317 2 0	
1,996	Mortgage Redemption Sinking Fund ..	—	
2,803			812 6 9
£57,076			£59,430 2 2

E. FUCHS, *President*

W. E. HARRISS, *Hon. Treasurer*

G. PARSLOE, *Secretary*

THE INSTITUTE OF WELDING

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31st MARCH, 1961

31.3.60		£ s. d.	£ s. d.
£			
	Administrative Expenses—		
7,732	Salaries	8,453 13 4	
635	Superannuation	877 10 9	
200	Pension	66 13 4	
868	Travelling Expenses	798 4 1	
154	Entertaining	159 19 4	
1,276	Printing and Stationery	1,411 2 11	
663	Postages	1,025 16 6	
86	Sundry Expenses	71 5 5	
36	Legal and Professional Fees	5 5 0	
157	Audit Fee	157 10 0	
348	Interest on Mortgage and Bank Overdraft	230 6 7	
12,155			13,257 7 3
	Establishment Expenses—		
416	Rates, Lighting, Heating, Cleaning, Telephone, *less* Rents Received	1,267 3 6	
680	Repairs and Decorations	1,008 1 6	
313	Depreciation (Furniture and Fittings)	329 0 10	
700	Depreciation (Property, 54 Princes Gate)	700 0 0	
250	Mortgage Redemption Sinking Fund	—	
2,359			3,304 5 10
	Direct Service to Members—		
2,787	Publications *less* Sales	836 6 5	
2,831	Library and Information Services	3,144 12 10	
2,546	Branch Expenditure	2,422 6 0	
324	Hire of Rooms and Meeting Expenses	450 1 2	
184	Examination Expenses	157 4 5	
290	Subscriptions to Scientific Societies	329 12 0	
8,962			7,340 2 10
—	Amount Transferred to Reserve for Future Development—School of Welding Technology		850 0 0
913	Balance—Excess of Income over Expenditure, transferred to Accumulated Fund		295 5 2
£24,389			£25,047 1 1

31.3.60		£ s. d.
£		
19,663	Subscriptions	19,844 6 0
659	Entrance Fees	754 13 9
112	Examination Fees	123 17 4
241	Interest Received	239 11 7
1,700	Contribution from International Institute of Welding	2,000 0 0
2,014	School of Welding Technology and Special Courses	2,084 12 5
£24,389		£25,047 1 1

REPORT OF THE AUDITORS TO THE MEMBERS OF THE INSTITUTE OF WELDING

We have obtained all the information and explanations which to the best of our knowledge and belief were necessary for the purpose of our Audit. In our opinion, proper books of account have been kept by the Institute so far as appears from our examination of those books. We have examined the above Balance Sheet and annexed Income and Expenditure Account which are in agreement with the books of account. In our opinion and to the best of our information and according to the explanations given us, the said Accounts give the information required by The Companies Act, 1948, in the manner so required, and the Balance Sheet gives a true and fair view of the state of affairs of the Institute as at 31st March, 1961, and the Income and Expenditure Account gives a true and fair view of the income and expenditure for the year ended on that date.

43 Bartholomew Close, London, E.C.1.
9th June, 1961.

GORDON EVANS & CO.,
Chartered Accountants.

The new procedure for ensuring closer liaison with the Institute's representatives on the technical committees of the British Standards Institute was put into operation during the year and consultations with representatives now take place at each meeting of the Technical Committee.

The first of the annual conferences on Welding Standardisation, referred to elsewhere, forms part of this reorganisation, which aims at focusing the specialist knowledge and experience of members on the vitally important task of standardisation.

Work has continued with the preparation of a number of publications listed above and a new *ad hoc* committee has been established to prepare a report on the welding of bars for reinforced concrete construction. A list of terms and definitions for the welding of thermoplastics, prepared by the Joint Committee on this subject, has received wide publicity in the technical press.

Library and Information Service

The use of the Service has continued at about the same level as last year. In May 1960, Miss W. R. Urwin resigned to take up a post with the Institute of Advanced Legal Studies and her place was taken in July 1960 by Dr. E. M. Sinclair. The three months' vacancy, followed soon after her appointment by the illness of the new Librarian, threw a heavy burden on Miss Pat Gray, the Library Assistant, whose devotion prevented any reduction of the service given to readers.

The following is a record of the use made of the Library during the year, the figures of the previous year being in parenthesis:

Loans:	Borrowers	625 (673)
	Items	1,182 (1,293)
Telephone enquiries:	Average per week	49 (53)
IIW Abstracts		174 (171)

Branches

All Branches maintained their accustomed activities during the year and held full programmes of meetings. In May 1960, for the first time for several years, a Conference of Branch Secretaries was held at the Institute. Most of the Branch Secretaries were able to attend and those who did so found the exchange of views among themselves and with the Institute's Officers of value, so that it is intended once more to make this an annual event.

Metal Spraying

Early in 1960 the Institute was approached by representatives of the two metal spraying associations and others interested in those processes with a welcome suggestion that they should establish a separate section on metal spraying within the framework of the Institute. Discussion between representatives of the Institute and of the metal spraying interests continued through the year and at the end of March the Council approved a scheme for the establishment of a metal spraying Division. Metal spraying has long been named among the allied processes for which the Institute accepts responsibility and the Council believes that the scheme for the establishment of a Division should widen the basis of support for the Institute and enable it to render valuable service to a branch of technology, the growing importance of which has already been recognised by the holding of a number of international conferences and the establishment of a Sub-commission on Metal Spraying within the International Institute of Welding.

Co-operation with Other Bodies

The British Welding Research Association and the Institute have worked together with enthusiasm in promoting the course on Welding Technology at the College of Aeronautics and in commending it to the support of industry. As mentioned above, representatives of both bodies took part in the Welding Mission to the U.S.S.R. A new agreement for the management of the *British Welding Journal*, which is the official organ of both the Institute and the Association, was reached during the year and is expected to lead to still more effective co-operation in the development of the *Journal*.

The work of the Institute's Secretariat on behalf of the International Institute of Welding and in the service of the Joint Committee of its British member societies continued along established lines.

Membership

At 31st March, 1961 the total membership was 4,815, made up as follows (the corresponding figures for 1960 are in parenthesis):

Honorary Fellow	1	(1)
Patrons	12	(12)
Fellow	1	(1)
Honorary Members	12	(12)
Members	850	(823)
Associate-Members	1,856	(1,811)
Companions	204	(184)
Graduates	215	(199)
Associates	1,344	(1,249)
Industrial Corporate Members		
Class 1	302	(301)
Class 2	14	(14)
Class 3	4	(4)
	4,815	(4,611)

The increase during the year was 204, compared with increases of 67 in 1959–60, 53 in 1958–9 and 21 in 1957–8.

During the year 357 (260) new members were elected, 33 (35) were transferred from one class of membership to another and 6 (8) were reinstated. The number of resignations was 58 (89) and 72 (84) members were removed from the register for non-payment of subscriptions.

The Council regrets to record the death of 29 (26) members.

Premises

The covenanted income of the Furnishing and Mortgage Redemption Fund and the Appeal to Industry Fund was again expended on improvements to the premises and their furnishing. A new machine room was constructed in the basement and other improvements were carried out in accordance with a five-year plan drawn up in 1958. Further improvements were made in the furnishing of the library and a start was made with the modernising of the office furnishings, many of which are old and well worn.

Finances

It is with great satisfaction that the Council is able to announce the redemption of the mortgage on the Institute's freehold premises at 54 Princes Gate. The final instalment of £2,000 was repaid in December 1960, less than four years after the purchase of the house.

Acknowledgments

Once more at the end of a year of increasing progress in many directions, the Council offers its thanks to all those who have assisted the Institute. In particular, it thanks the subscribers to the two Appeal Funds, the lecturers in the School of Welding Technology and their employers, the authors of papers and reports presented at the Institute's meetings, the members of its committees, sub-committees and reporting groups, the honorary officers and committee members of the Branches.

The Council also thanks the staff of the Institute for another year of loyal and devoted service.

Welding RESEARCH

B.W.R.A. REPORT

Brittle Fracture Strengths of Welded and Notched 3 in. Thick Steel Plates

By A. A. Wells,
B.SC.(ENG.),
PH.D., A.M.I.MECH.E.

The report briefly describes the development of 2,000-ton testing equipment for the fracture of notched and welded normalised low carbon steel specimens 37 in. wide and 3 in. thick. It discusses tests on twenty manually welded specimens, some of which were furnace stress-relieved. By comparison with tests on similar specimens from 1 in. thick plate of closely similar Charpy V notch properties, it is shown that fracture stresses and extensions as large as those in the thinner material are only achieved when the artificial defect is within the middle third of the 3 in. plate. Defects of equal area in the two thicknesses and disposed near the surfaces of the thicker plate are shown to give appreciably lower fracture stresses and extensions in the thicker plate.

Within the temperature range studied, stress-relieved specimens in the 3 in. thick material, although showing high strength, were of lower ductility than were similar 1 in. thick specimens.

Some extraneous fractures at the transversely loaded end butt welds between specimen and testing equipment exposed a hitherto unrecognised mode of low stress fracture, running from end to end of the weld through part, only, of the plate thickness and showing preference for the plane between weld and parent plate, having been initiated by weld defects in this plane.

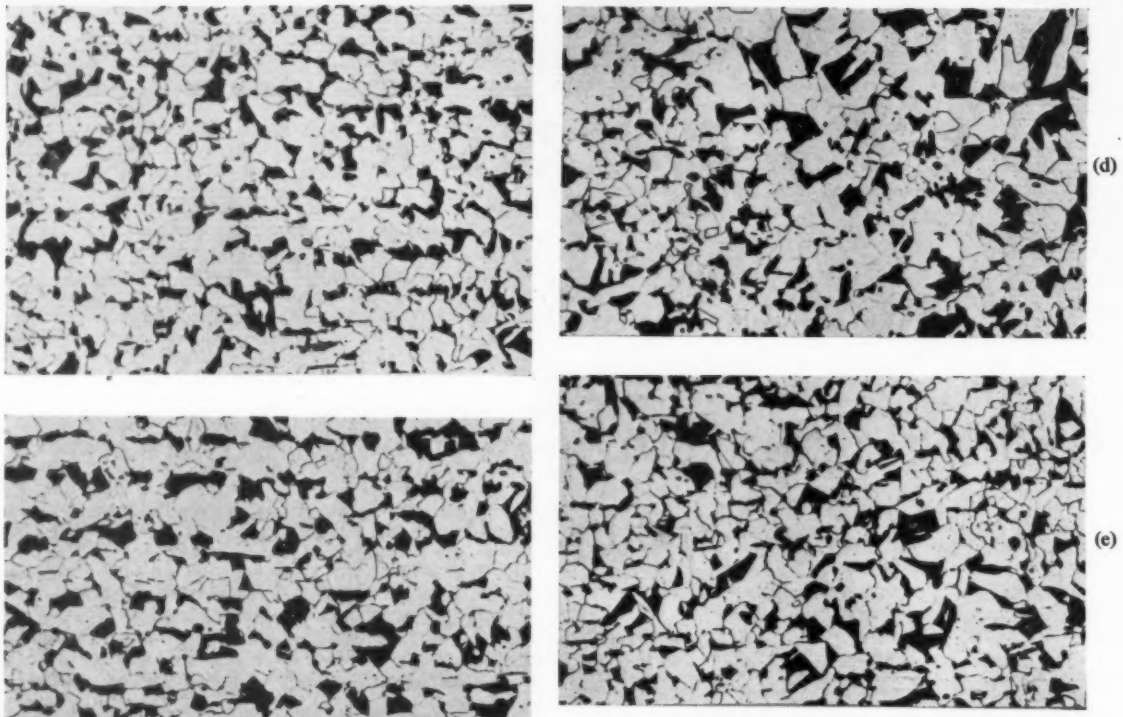
Introduction

SEVERAL previous papers[1–5] have described the conduct of wide plate tensile tests on low carbon steel specimens whereby low stress brittle cleavage fractures were produced in simulation of conditions that might arise in a casualty. Important features to assist the achievement of low stress fracture in this type of laboratory test were:

(i) A central butt weld in the test plate in the direction of tension, with sufficient width of plate on either side to provide a heat sink during welding and to suppress longitudinal contraction from welding
(ii) A sawcut notch in the edges prepared for the butt weld, of a depth at least sufficient to obviate melting out during welding
(iii) A test temperature appropriately chosen to be below the transition temperature of the parent material as, for instance, measured by the Charpy V-notch test.

From these and ancillary tests it has been made clear that the plastic deformation about the notch, contributed thermally by the welding operation, makes possible the early initiation of cleavage fracture, and that the longitudinal tensile residual stresses from the same cause materially assist the early stages of crack propagation from the artificial notch. Moreover, stress-relieving at 650°C. has been shown to restore yield point strength and a measure of ductility to notched and welded plates, while mechanical stress-relieving restores only the yield point strength, at temperatures as far as 100°C. below the fracture appearance transition temperature of the parent material.[3,5] Until recently most of the work revealing this behaviour had

Report B7/4/60 of the British Welding Research Association, circulated to members in September 1960.
Dr. Wells is Assistant Director of Research of the Association.



1—*Micrographs of 3 in. and 1 in. thick steel plate:* (a) *Sub-surface 3 in. thick plate 1;* (b) *mid-thickness 3 in. thick plate 1;* (c) *sub-surface 3 in. thick plate 2;* (d) *mid-thickness 3 in. thick plate 2;* (e) *mid-thickness 1 in. thick plate 3* ×100

been confined to plates up to 1 in. thick. In nuclear power, pressure vessel and general industry low carbon steel plates of much greater thickness are used in the welded condition. Strenuous efforts are made by steelmakers to maintain the level of notch ductility in thick plates equal to those in thinner plates, and by others to maintain the quality of welded joints with increased plate thickness. However, the yardstick by which the maintenance of conditions with increased thickness is assessed is often concerned, like the Charpy test, with extracted specimens of constant size, whereas the mechanical stress conditions themselves are suspected of becoming more severe with size increase. A need existed for the demonstration on full scale of notched and welded plate behaviour with plates at least 3 in. thick.

Tensile Testing Equipment

An equipment for producing tensile loads up to 600 tons on these specimens has been described,[6] and during four years continuous development this has been proved for regular use at a maximum load of 700 tons, or occasionally at 750 tons. This equipment is fully capable of producing brittle cleavage fractures in 1 in. thick low-carbon steel plates even at temperatures down to −80°C., where yield strengths are significantly larger than those of their ambient temperature counterparts. It was thus necessary to provide equipment of approximately 2,000 tons capacity to fracture 3 in. thick low carbon steel plates. The equipment to a design developed by B.W.R.A., and manufactured and donated by Babcock and Wilcox Ltd. is described in an appendix to this report. The manner of use differs negligibly from that of the earlier equipment and needs no further description.

Material

When actual low temperature operation is excluded, a general demand exists in industry, notably for pressure vessel construction for good quality thick

low carbon-manganese steel plates with a transition temperature sufficiently low to ensure the possibility of low stress cleavage fracture resistance during fabrication at ambient temperatures not below 0°C. Although with care it would be possible, by adopting normalising or other procedures, to achieve such conditions with balanced or semi-killed basic open-hearth steel, as made in the U.K., it is regarded as good practice to use a fully killed steel. Normalised silicon killed carbon manganese steel of boiler quality is widely used in industry, and such a composition was chosen in conjunction with the Committee, for initial work at 3 in. thickness.

Portions of the same cast to a gas-cooled nuclear reactor vessel specification (JTA101) were rolled specially to 1 in. and 3 in. thickness, normalised and donated by Colvilles Ltd. The ingot for the thicker material was divided into two slabs, each of which was rolled to the dimensions 148 in.×76 in.×3·1 in. Chemical analyses were made at positions at the end of each of the three slabs, and these are given with extreme values in Table I.

The cast analysis was within these extreme values for each element and, with the degree of uniformity shown, no orderly pattern of segregation could be observed. Tensile tests with 0·564 in. dia. specimens were also performed at the same positions, and the results are given in the same way in Table II.[7]

Table I

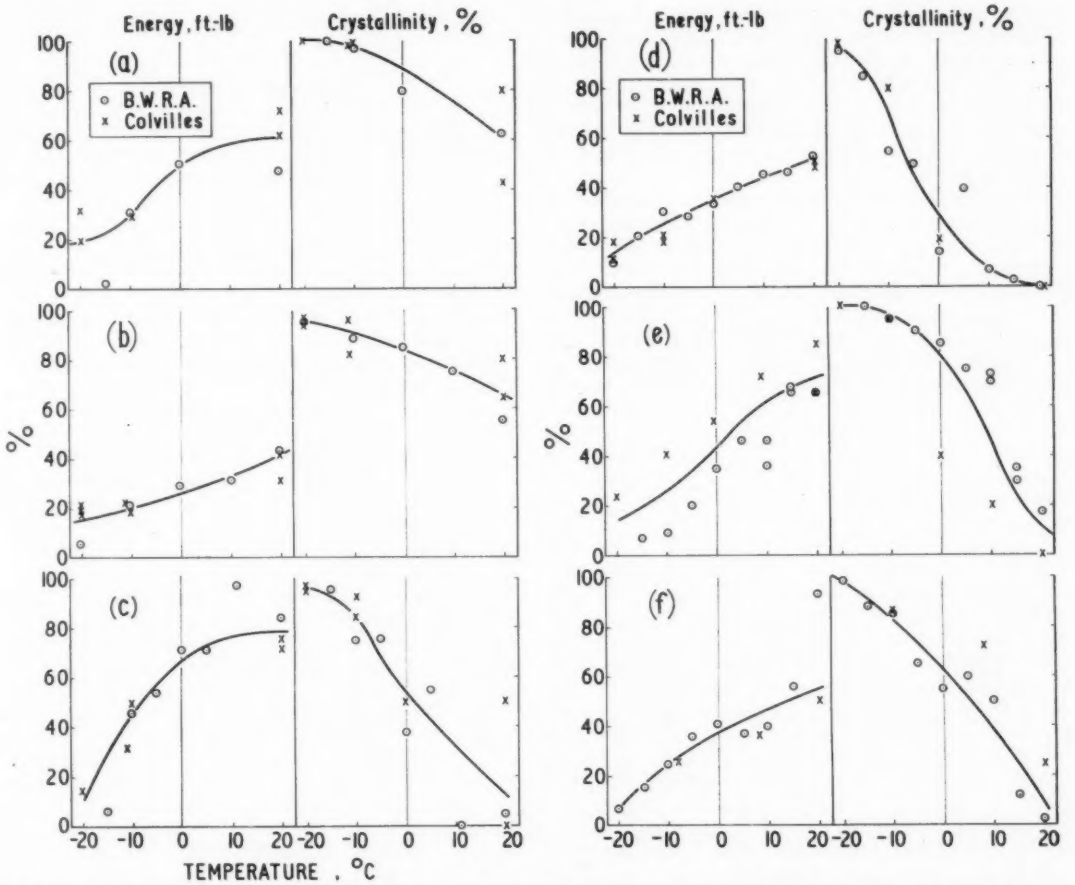
Analysis of steels

	Composition, %								
	C	*Si*	*S*	*P*	*Mn*	*Ni*	*Cr*	*Mo*	*Al*
Lowest	0·125	0·13	0·030	0·019	1·12	0·10	0·08	0·03	0·02
Highest	0·15	0·16	0·034	0·029	1·16	0·11	0·10	0·05	0·02

Table II

Results of tensile tests

	Proof Stress, tons/sq.in.				*U.T.S., tons/sq.in.*	*Elong. on 2 in. (4√A), %*	*Red.in Area, %*
%	0·05	0·2	0·3	0·5			
Lowest	16·5	16·3	16·4	16·4	28·0	28	38
Highest	17·7	17·6	17·7	17·8	29·9	39	62



2—*Charpy V-notch test results:* (a) *3 in. longitudinal sub-surface;* (b) *3 in. transverse sub-surface;* (c) *3 in. longitudinal mid-thickness;* (d) *3 in. transverse mid-thickness;* (e) *1 in. longitudinal;* (f) *1 in. transverse*

Table III

Transition temperatures

Plate Thickness, in.	Position	Longitudinal 15 ft-lb.	Longitudinal 75% cryst.	Transverse 15 ft-lb.	Transverse 75% cryst.
		Temperature, °C.			
1	Mid-thickness	−19	3	−15	− 4
3	Mid-thickness	−19	−7	−19	−11
3	Sub-surface	−22	9	−20	10
Average		−20	2	−18	− 2

In this case the higher elongations and reductions in area belong to the thinner material; for the other properties extreme values emerge randomly from either thickness. The steelmakers' micrographs are shown in Fig. 1. Again there is no marked disparity between plate positions or thicknesses.

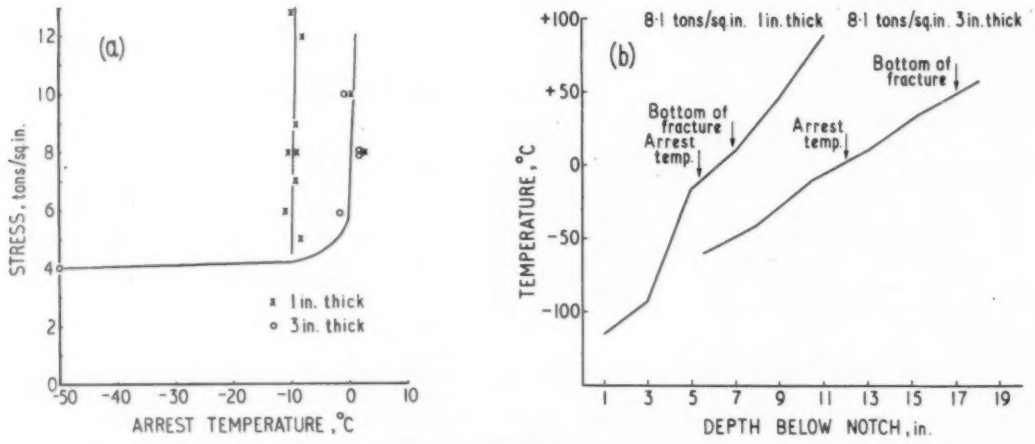
Full Charpy V-notch curves of energy absorption and crystallinity against temperature were independently prepared by the steelmakers[7] and the investigators, for positions at the mid-thicknesses for 1 in. and 3 in. plates and additionally at planes midway between surface and mid-thickness for the 3 in. plates with both longitudinal and transverse specimens. 15 ft-lb energy absorption and 75% crystallinity temperatures from the combined results are given in Table III, and the curves are reproduced in Fig. 2. Except in one of the twelve curves there is no regular disparity between the laboratories, and this isolated occurrence may have arisen from differences in sampling position.

The uniformity of the material may be judged as good for the purpose of the research, there being less variation between the thicknesses than due to position in the thicker plate. The variation within the thick plate is regular, and confined to the fracture appearance transition temperature, which is higher at subsurface than mid-thickness. The difference between the longitudinal and transverse results is negligible except for peak energy absorptions with ductile fracture, which are lower for transverse specimens, as is usual.

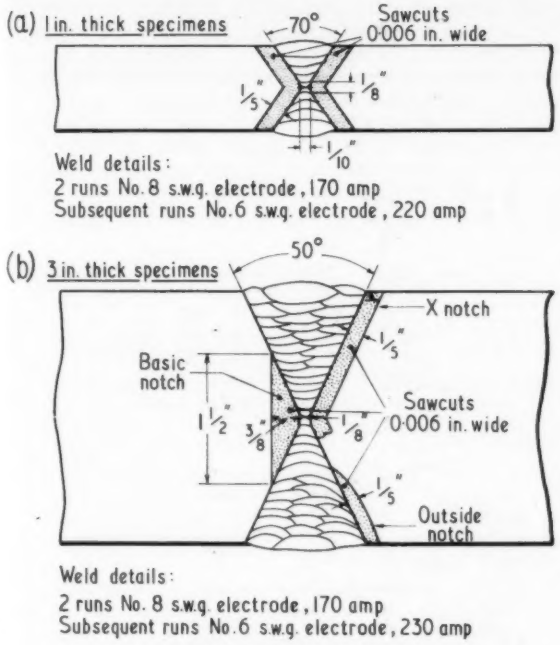
Temperature gradient Robertson crack arrest tests were performed by the steelmakers[8] on samples of both thicknesses of material retained for this purpose. By implication, the specimens were loaded in tension in the direction of rolling, but testing machines differing in load capacity were used for the two thicknesses. However it has been shown by previous work that the essential characteristics of the results were the same for both machines, when testing similar specimens. The same size of initiation knob was used for both thicknesses, but whereas the specimen size was $3\frac{3}{4}$ in. $\times 12\frac{1}{2}$ in. for the 1 in. plate, that for the 3 in. plate was 6 in. $\times$ 20 in. Positions and temperatures for crack arrest were determined both for the surface shear lip and for the centre of plate. In most cases at low applied stress these did not differ by more than 10°C., but at higher applied stresses differences up to 50°C. were recorded. In conformity with Robertson's interpretation based on additional isothermal tests the positions of shear lips were used preferentially to determine crack arrest temperatures, and these values are plotted against applied tensile stress for both thicknesses in Fig. 3. Under these conditions the arrest temperature for the 3 in. plate appears to be 0°C., and that for the 1 in. plate is less than 10°C. lower. The disparity between thicknesses is again quite small.

Specimen Preparation

Although the specimens were originally intended to be 37 in. wide and 36 in. long, with a central double-V notched weld, modifications were made to facilitate testing. In particular, the central 28 in. length of each was waisted to a width of 32 in. to reduce the cross section to permit fracture of the strongest specimens, which required fracture loads up to 2100 tons. To give a measure of protection from brittle fracture to the massive end fittings, 4 in. wide and thick extension plates were butt-welded to them, and the assemblies were normalised and water quenched to 650°C., followed by a period at this temperature for stress-relieving.



3—*Robertson test results*



4—Weld preparations and types of notch

The aggregate length of each specimen to be welded to the end fittings then amounted to 28 in., but this was regarded as sufficient to permit the production of full residual stress at the cente of the longitudinal weld.

In deciding on the type of longitudinal test weld and associated artificial defect to be adopted, equal attention was given to maintaining the continuity with earlier tests on 1 in. plate, and to accepted good practice for butt-welds in 3 in. plate. The double-V preparation for the thicker plate, shown in Fig. 4 was chosen in this way. For the current 1 in. plate tests, the already established double-V weld preparation and form in the prepared edges for the sawcut notch were used. After preliminary tests of alternative notch forms for the thicker material, performed with limited size specimens in longitudinal bending relative to the welded joint, it was decided to adopt a pair of sawcuts of comparable area to those used in 1 in. thick plates, but disposed as in Fig. 4, so as to embrace the central half thickness of the plate only. The importance of notch location, not realised at the outset, emerges later in this report, from the variations introduced at a later stage. With regard to weld metal, the preference for a basic low hydrogen electrode coating is usually considered to be greater as plate thickness increases, and special electrodes have been developed for thick material. On the other hand, although automatic welding is used for thick material as it is for thinner, manual welding of 3 in. thick material is widely employed, particularly on account of its facility in multi-position work. All the wide plate testing so far carried out in the author's laboratory has been in conjunction with manual welding and it was not considered appropriate to change at this stage. The balance of requirements was met in the present case by a choice for alternate specimens of E319 (BS.1719) rutile-coated electrodes and E615 low-hydrogen basic-coated electrodes. Recent changes in the manufacture of the latter general type of electrode were not reflected, since the electrodes were supplied as a special batch to maintain continuity with the earlier work. The changes referred to are partly associated with production of deposits of lower transition temperature to meet current requirements, but it was recognised that this feature has not hitherto assumed importance in wide plate testing, under conditions where the weld metal is mainly already superior in this quality to the heat-affected zone in the parent plate. On the other hand the E319 and E615 deposits have differed markedly in their susceptibility to cracking in the sawcut plane during cooling and this feature has influenced the total flaw size and the brittle fracture strength as a consequence. The numbers, sizes and dispositions of runs, with approximate currents are shown in Fig. 4. Slight differences were accepted in the numbers of runs characteristically used by each of the individual welders. No special precautions were taken either on preheat or interpass temperature, but all electrodes were kept dry before use under controlled recommended conditions, and welding was performed under cover.

The treatment for the stress-relieved specimens was subject to control from thermocouples on the specimens, and the following cycles were employed:

Ambient to 650°C. in 4½ hr
1 in. thick 650°C. for 1 hr
3 in. thick 650°C. for 3 hr
650°C.–300°C. in 4½ hr

A production technique was devised for the butt welds between specimens and end fittings to cope with the special requirements at this position, namely, maintenance of alignment, speed and economy in deposition and suitability for repeated cutting out and remaking the welds. An H preparation was used commencing with machine gas cuts normal to the surface. The preparation on each side was then converted to a double-J by addition to each face of central bars of ½ in. × ¼ in. section, attached with pairs of full fusion fillet welds, using E615 basic coated low hydrogen electrodes. In later specimens the sides of the J preparations were sloped with further runs of weld metal in order to reduce the risk of slag entrapment at the side wall when depositing after butting the ends together.

In making these welds it was found to be more economic with the equipment available to fill the welds using manual welding and Class 9 iron powder coated electrodes at currents up to 600 amp (4 gauge electrodes), than to employ submerged-arc welding. The short length of the welds, with the necessity to keep their ends under control without using run-off tabs and the need to keep continuous control of alignment had much to do with this decision. All filling was done in the downhand position, using a simple trunnion manipulator on which the end fitting and test plate assembly could be poised to permit balanced welding on both sides of the roots. The positioning was maintained with minimum restraint in order that alignment could be continuously observed. In spite of control, alignment was lost on a few

Table IV

Wide plate test results

Spec. No.	*Weld Detail*	*Orig. Flaw Area, sq.in.*	*Test Temp., °C.*	*Fracture Srength, tons/sq.in.*	*Crack Length, in.*	*Pre-fracture Extension* $\times 10^{-4}$	
1 in. thick							
W1/1	L.H	0·37	−20	19·3	T	6	
W1/2	R	0·40	−20	9·4	T	None	
W1/3	L.H	0·37	−15	19·2	T	None	
W1/4	R	0·49	−10	19·26	T	45	
W1/5	L.H	0·42	−10	19·6	T	6	
W1/6	R	0·51	−10	23·3	T	146	36 in. wide spec. at −10°C. Unbroken
			−20				30 in. wide spec. at −20°C. Ductile tear 2·2 in. long.
W1/7	R	0·38	+ 1	18·6	T	59	
W1/8	R	0·45	+ 5	max. appd. stress 22·97	Unbroken	266	Discontinued when ductile tear reached 3·0 in. length
W1/9	R	0·47	+11½	max. appd. stress 24·0	Unbroken	292	Discontinued when ductile tear reached 2·8 in. length.
			+15½				
W1/10	R Stress-relieved	0·50	−29½	21·95	T	178	
3 in. thick							
W3/1	L.H	0·48	−45½	21·0	T	6	Rough branching fracture. Reflection markings.
W3/2	R	1·6	−45	2·3	4·6	0	Divided fracture.
				16·8			Extensive oxidised precracking.
W3/3	L.H	0·54	−30	19·1	T	4	Smooth fracture with reflection markings.
W3/4	R	0·80	−30	13·1	T	None	Smooth fracture
W3/5	R	0·75	−23	19·1	T	9	Reflection markings.
W3/6	L.H	0·53	−20½	20·5	T	4	Reflection markings.
W3/7	R	1·24*	−20	3·8	4·9	None	Oxidation colouring visible on one half only.
				19·0	one side only.		
W3/8	R	0·82	−15	max. appd. stress 19·2	T	12	Reflection markings.
				17·7			
W3/9	R	1·22	−10	6·53	T	None	Divided fracture with smooth texture.
W3/10	R	0·56	+½	19·6	T	151	
W3/11	R	0·68	+4¾	19·20	T	13	Reflection markings.
W3/12	R	0·64	+12	22·1	T	188	Tested at temps. between +12 and +15. Preceded by 2·8 in. dia. ductile tear. Very rough.
W3/13	R X notch	7·0	−10	0·0			Post weld crack.
				17·0	T	None	2·3 in. long.
W3/14	L.H X notch	1·97	−10½	6·1	6·5	None	Divided fracture smooth texture.
				19·6	T	4	
W3/15	R Outside notch	0·68	−10½	3·8	5·1	None	Terminated by end weld fracture.
				>20·0	T	Not known	
W3/16	R Outside notch	0·68	−8½	0·0	1½ in.		Three-stage low stress short crack.
				5·5–6·0	14	None	1½ in. radius semi-circle around notch whilst cooling −8½°C.
			−10	22·5	T		
W3/17	R Stress-relieved	0·58	−44	18·2	T	31	Intermediately rough (1 Branch). Sawcut unoxidised but minor pre-cracking.
W3/18	R Stress-relieved	0·52	−29·5	19·3	T	12	Very rough, branching fracture. Sawcut unoxidised.
W3/19	R Outside notch Stress-relieved	1·15	−32	28·3	T	254	Intermediately rough.
W3/20	R Stress-relieved	2·44	−15	18·25	T	6	Extensive precracking.

occasions, and was regained by arc air gouging. Broken specimens were removed by machine gas cutting, simultaneously producing edge preparations on the end fittings for the next welds. To reduce the risk of superimposing defects the successive welds were never placed at exactly the same positions, the shift first to one side and then the other being arranged with steps of approx. ½ in. with a total movement of +¾ in. In spite of careful development and control of this phase of manufacture, some end weld fractures occurred during tension testing. These fractures contributed ancillary information and are separately described.

Loading

The methods employed differed little from those described earlier.[5] Crushed solid carbon dioxide was used for cooling, in boxes permitting direct contact with each specimen towards its ends, so that the centre would not be subject to local temperature disturbances, and would remain accessible. Temperatures at

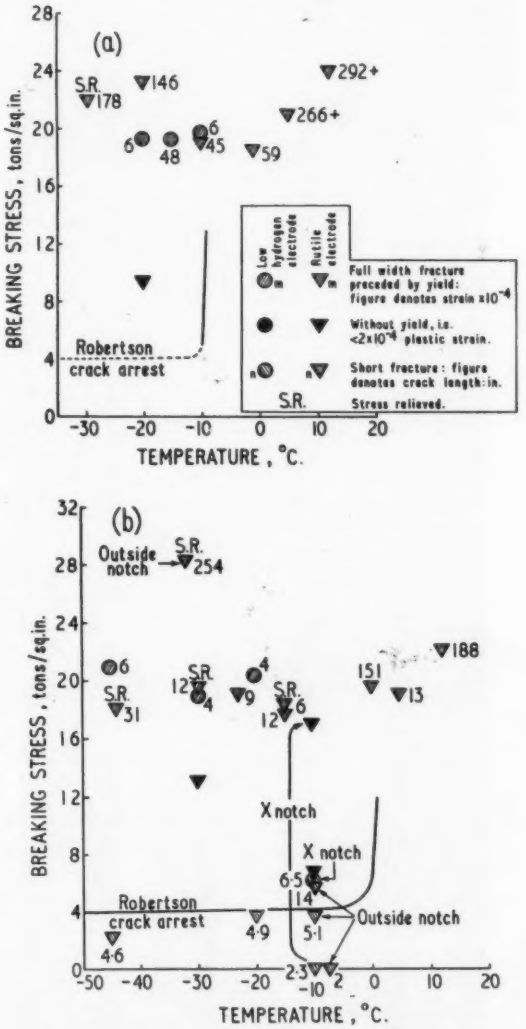
the top, middle and bottom of the specimen in the cracking zone were registered continuously during test, so that control could be achieved. Wire resistance strain gauges were cemented near the ends of the original sawcuts to act as short crack event markers. Autographic measurements of specimen load and overall extension were maintained. The rate of stress increase during loading was maintained the same for both thicknesses of specimen, although different end fittings and numbers of loading capsules were in use.

Results

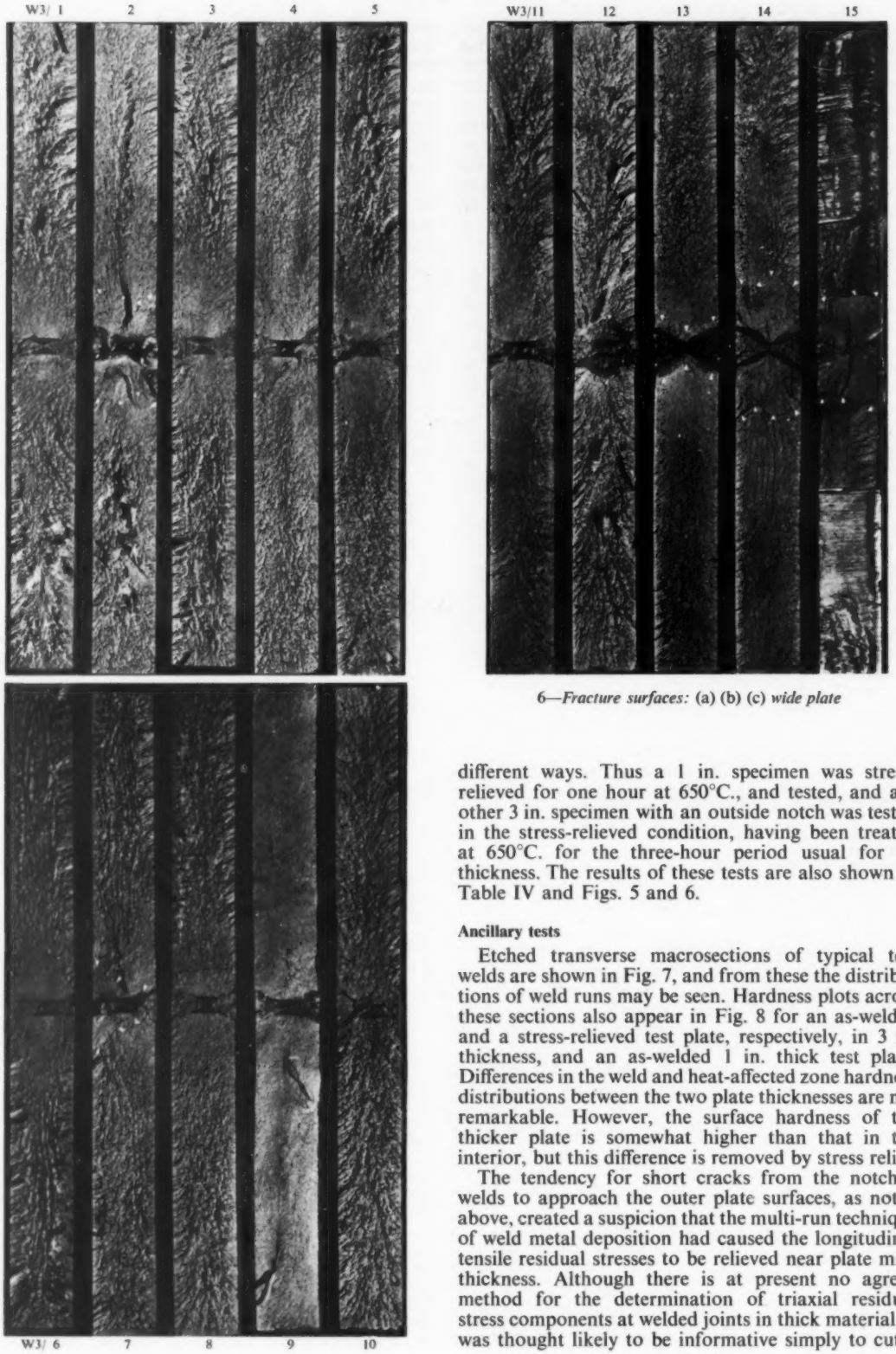
Information obtained from all the wide plate tests is summarised in Table IV. The testing temperatures shown are mean values from the three thermocouples on the cracking plane, and in most cases are not subject to any dispersion greater than $\pm\frac{1}{2}$°C. The fracture stresses represent in all cases the recorded loads divided by the net area of cross section on the fracture plane for the condition immediately prior to fracture. In the case of fracture directly from the sawcuts, it should be pointed out that the net and gross specimen cross section areas are negligibly different. The flaw areas indicated are those of the original sawcut, together with any precracked weld metal surface observed by the presence of oxidation colours. It should be recognised that there is some uncertainty about this, since on one specimen weld metal oxidation colouring was present only on one of the two fracture faces. Moreover, in the stress-relieved specimens of 3 in. thick material, oxidation, even of the sawcuts, had vanished when the fracture faces were opened. Fracture strengths for the 1 in. and 3 in. thick specimens are plotted against testing temperature in Fig. 5. The key to this diagram is the same as has been used before,[5] and the Robertson crack arrest curves have been added. The results for stress-relieved specimens, and others with modified sawcut notches have been added. Photographs of fracture surfaces are given in Fig. 6.

Many of the same features appear in the present results as in those described earlier. Evidence of weld metal and heat-affected zone precracking in some specimens, low stress short fractures, low stress through fractures, reinitiated fractures preceded by general yield, and rough fracture textures for those specimens fractured at high applied stresses are all represented. The fracture strength and temperature curves of Fig. 5 do not, at first sight, show large differences in behaviour between the two thicknesses of material, and the behaviour depicted for the 1 in. plates is comparable with that shown earlier[5] for steel *Q* or possibly steel *R*. New features emerge, however, for the 3 in. thick specimens. Firstly, the fractures occurring at high applied stresses show, on the whole, comparably less prefracture plastic deformation, and this is especially noticeable for the stress-relieved specimens. Secondly, all the low stress fractures, without exception, showed early stages of fracture dividing into halves, meeting with a slight step at plate mid-thickness. This immediately suggested that crack initiation occurred preferentially at the ends of the notches, towards the plate surfaces, rather than from the centres. This evidence was strengthened by the low stress fracture specimen W3/7, where weld metal precracking with oxidation colouring was detected to a distance closer to the plate surfaces than in other specimens with central sawcuts, and the resulting short crack occurred to one surface of the plate only. The tests performed with sawcut notches through full plate thickness (W3/13 and 14), as used for the 1 in. thick specimens, and with outside notches only (W3/15 and 16) provide further confirmation as to the relative ease with which fracture initiated in all four cases. When compared on the basis of those as-welded specimens notched to the plate surfaces it is seen that all 3 in. plates gave low stress or spontaneous fractures, while all but one of the 1 in. plates tested in the same temperature range gave yield-point fractures. The difference is quite significant.

To explore the differences in behaviour exposed for the 3 in. plates, remaining specimens were tested in



5—Wide plate fracture strengths: (a) *1 in. thickness;* (b) *3 in. thickness*



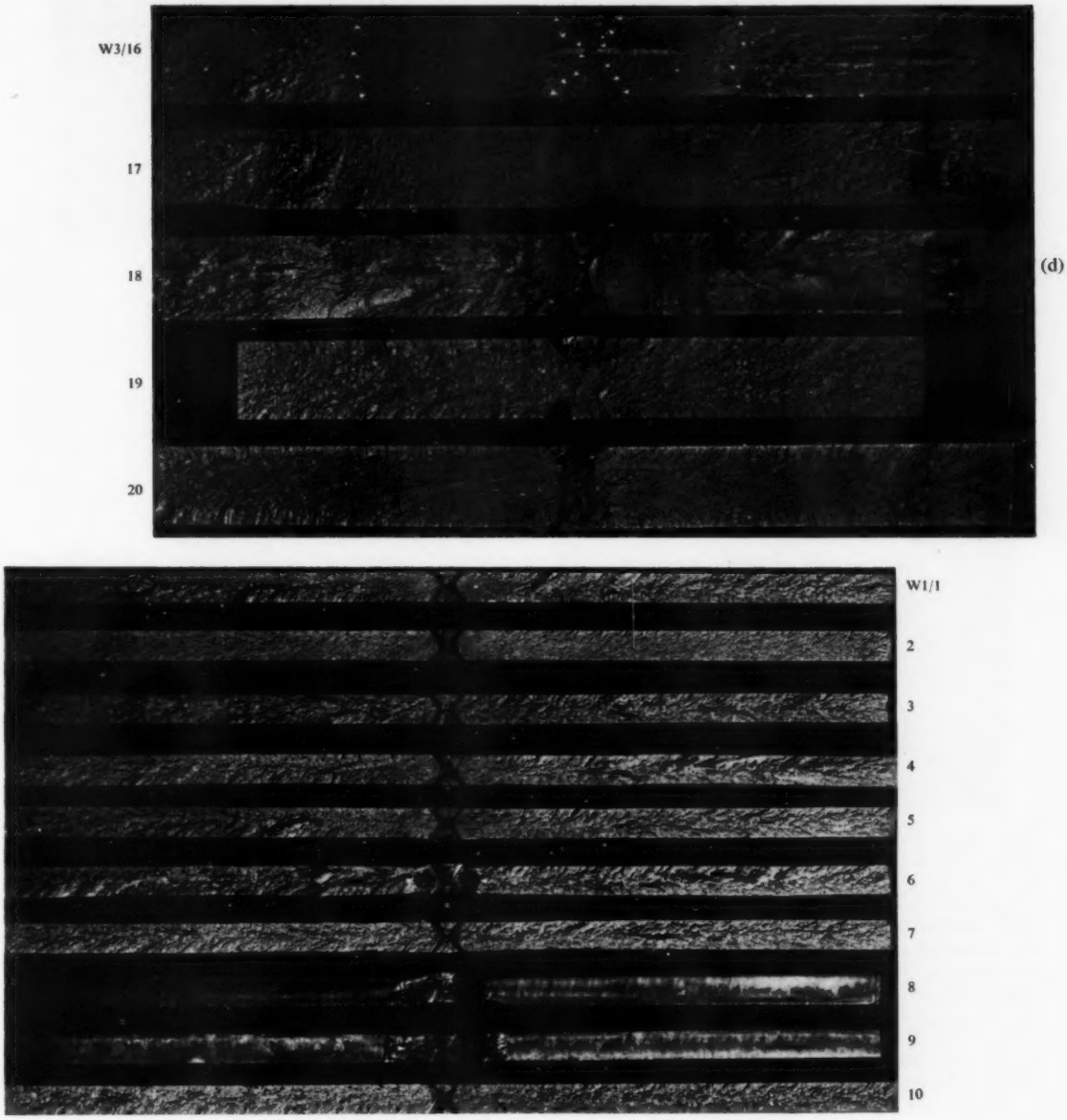
6—*Fracture surfaces:* (a) (b) (c) *wide plate*

different ways. Thus a 1 in. specimen was stress-relieved for one hour at 650°C., and tested, and another 3 in. specimen with an outside notch was tested in the stress-relieved condition, having been treated at 650°C. for the three-hour period usual for its thickness. The results of these tests are also shown in Table IV and Figs. 5 and 6.

Ancillary tests

Etched transverse macrosections of typical test welds are shown in Fig. 7, and from these the distributions of weld runs may be seen. Hardness plots across these sections also appear in Fig. 8 for an as-welded and a stress-relieved test plate, respectively, in 3 in. thickness, and an as-welded 1 in. thick test plate. Differences in the weld and heat-affected zone hardness distributions between the two plate thicknesses are not remarkable. However, the surface hardness of the thicker plate is somewhat higher than that in the interior, but this difference is removed by stress relief.

The tendency for short cracks from the notched welds to approach the outer plate surfaces, as noted above, created a suspicion that the multi-run technique of weld metal deposition had caused the longitudinal tensile residual stresses to be relieved near plate mid-thickness. Although there is at present no agreed method for the determination of triaxial residual stress components at welded joints in thick material, it was thought likely to be informative simply to cut a

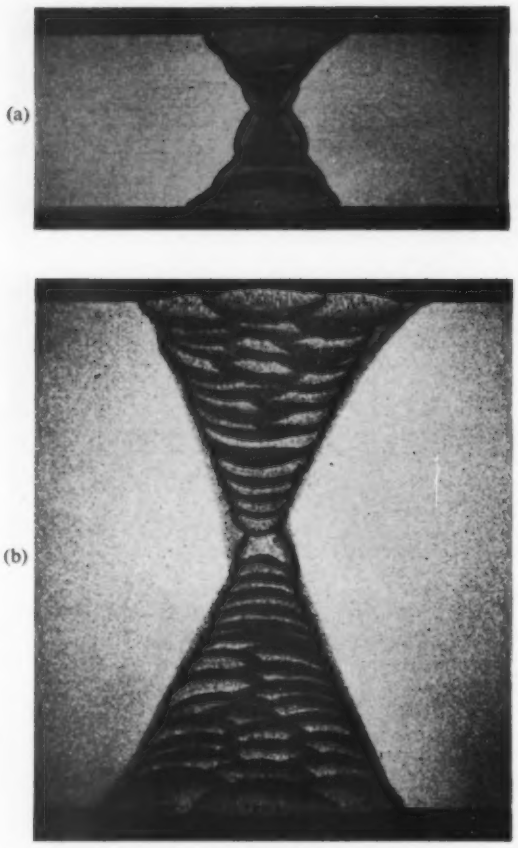


6–Fracture surfaces: (d) *3 in. thick plate;* (e) *1 in. thick plate*

representative welded test plate into strips, and to measure the resulting elastic recoveries of the strips by micrometer. Nevertheless, it was recognised that the method, although giving accurate measurements, would permit no estimation of true longitudinal or transverse residual stress components. In spite of this the distribution of longitudinal elastic recoveries of the strips shown in Fig. 9. demonstrates beyond all reasonable doubt that relaxation of longitudinal tensile residual stress at the weld root has occurred, presumably due to the influence of the subsequent runs deposited on each side. It is interesting to contrast the situation with that demonstrated by Soete[9] for a single run electro-slag weld, where the mid-thickness tensile residual stress is shown to be larger than that at the surface. A further interesting result is that the overall width of the residual tension zone in the thick plate is apparently no greater than that for a 1 in. plate.[2]

Fractures in end attachment welds

It is not surprising with highly stressed testing equipment, operating for most of the time below the transition temperature of its component parts, and with test plates continually being gas cut from it and rewelded to it, that there should have been occasional

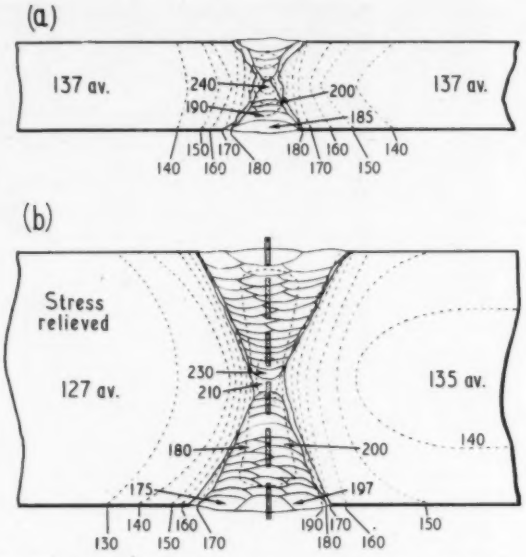


7—*Transverse sections of welds:* (a) *1 in. thick plate;* (b) *3 in. thick plate*

brittle fractures other than of the test plates. The few that occurred are informative, since they amount to true casualty fractures with the opportunity for the history of each to be recorded. One in particular is described.

Specimen W3/15 was loaded at −10°C., and a short crack, at the expected position, was produced in it at 3·8 tons/sq.in. Before final fracture took place a transverse end fracture intervened at an applied stress of 6·3 tons/sq.in., to partial depth as had been observed once before. On this occasion the fracture was fully radiographed before being cut out for repair. Although the radiograph did not show without ambiguity the origin of fracture, an appreciable length of it was along the fusion line between the last made weld and the old weld metal on the end fitting extension piece, to which the joint had been made.

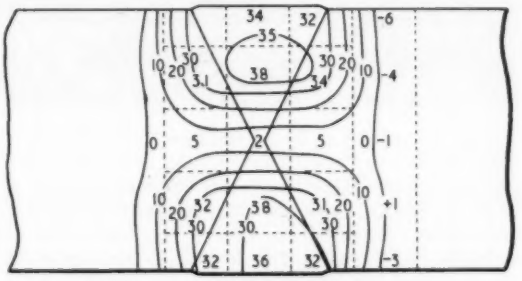
The specimen was cooled to the same temperature and reloaded after repair, but on this occasion the recently rewelded end fractured again at an applied stress on this section of 15 tons/sq.in. This time the fracture was complete but of interesting contour and is shown in Fig. 10. Again it will be seen from chevron markings to have propagated from end to end on one side of the plate only, in the plane between weld metal



8—*Hardness traverses of transverse welds:* (a) *1 in. thick plate;* (b) *3 in. thick plate*

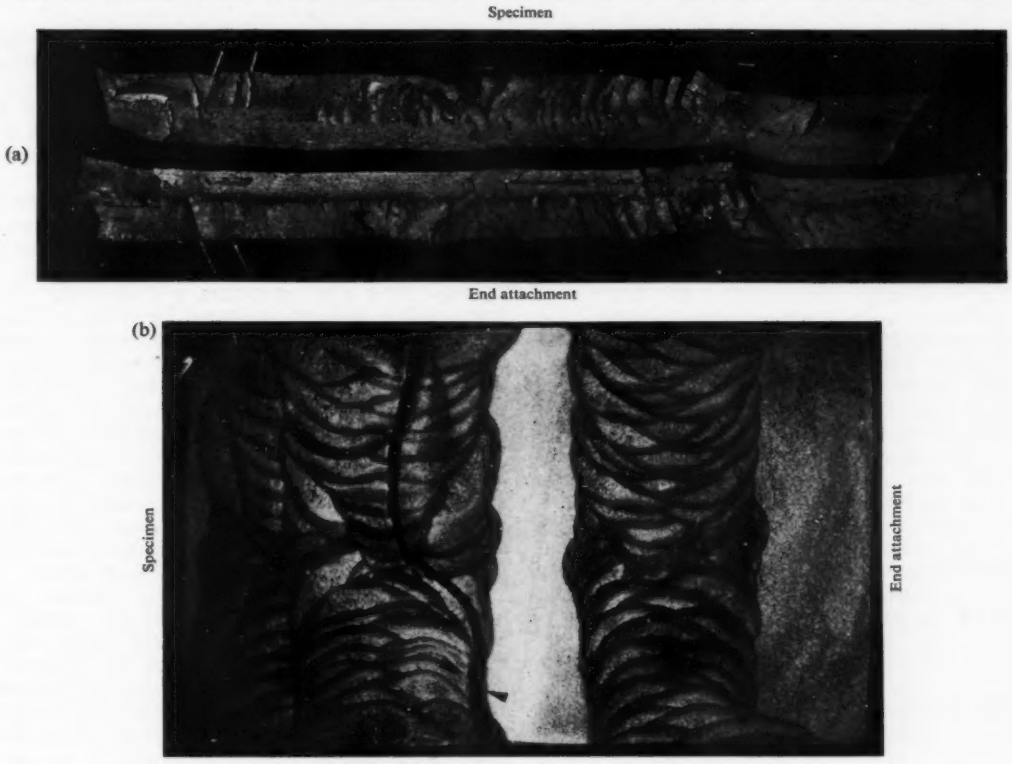
and original parent metal of the end fitting extension, but in this case the load at the time of fracture was sufficient for severance to be completed. After complete fracture along one side the movement of the crack front was predominantly through the thickness, but by means of a path first turning into the plane of the plate and then passing out to the opposite surface in the direction normal to it through the middle of the weld. This is shown in the macro-etched transverse section of Fig. 10.

The source of fracture was an area of slag entrapment, apparently along the original prepared edge of parent plate, and of size 2 in.×$\frac{3}{8}$ in. It is doubtful whether the slag entrapment was also involved with lack of fusion of the underlying parent metal. Other areas of similar slag entrapment appear elsewhere in



Elastic Recovery 0·001 in. units	Equivalent Residual Stress, tons/sq.in. Uniaxial	Biaxial	
−10	4·6	6·0	Compression
0	0	0	
10	4·6	6·0	Tension
20	9·2	12·0	,,
30	13·8	18·0	,,
35	16·1	24·0	,,

9—*Elastic recovery of longitudinal weld sections released by slitting, and approximately derived equivalent residual stress system*



10—*Brittle fracture of transverse end attachment weld*

parts of the fracture lying in the same plane. On returning to the original radiographs these areas of planar defect can just be seen but they were not seen at the time when the repair was due to be made. It is quite clear that the region now fractured had survived many previous thermal cycles from welding the test plates to the end attachment.

The possibility so revealed of the occurrence of low stress brittle cleavage fracture along a weld-metal/heat-affected-zone interface from a common planar weld defect, following thermal plastic cycling along the weld, is thought to be worth further investigation.

Discussion

In view of the close comparison that may be made between Charpy V-notch results for the two thicknesses of material it is evident that the difference between the fracture-stress/temperature results for the 1 in. and 3 in. thick wide plates must be attributed mainly to mechanical or geometrical effects. It may also be recognised that the change in initiation behaviour between the two thicknesses is somewhat more pronounced than that for propagation. Thus, the total extension to fracture with the 3 in. plates tends to be less than for 1 in. plates, but the short cracks at any given value of applied tensile stress do not seem to extend much further before arrest in the thicker material as compared with the thinner. The latter behaviour is reasonable in the light of current knowledge of fracture mechanics, and primarily two dimensional stress distributions.

The total width of the longitudinal tensile residual stress field has not been observed to be appreciably greater for the welds in 3 in. plate than for those in the 1 in. plate, This also is understandable if the heat flow conditions giving rise to residual stress are recognised to be dictated mainly by the individual weld runs, as they are laid down. With such a residual tension field a little wider in the 3 in. plate case, but compensated by some reduction in stress towards plate mid-thickness, the mean value total residual tensile load per unit thickness would be about the same in the two thicknesses, and the distributions of crack extension force would then also be the same for given values of externally applied tensile stress.

An explanation for greater ease of crack initiation in the thicker material would be plausibly connected with the generation of larger values of tensile stress through the thickness in the 3 in. plate case. Irwin[10] has recently pointed out with regard to conditions at a plane notch that the ratio to characterise this effect is the length in the direction of crack travel of the plastic zone at the notch tip, divided by plate thickness. When this ratio is already small, plane strain conditions predominate, and no larger through-the-thickness tensile stresses are generated for further increase in plate thickness. Similarly, when the ratio is large, plane stress predominates, and there is also a lack of sensitivity to thickness change. Greatest sensitivity to change of plate thickness can be expected when the

ratio is of order unity. This effect may explain the contrasting effects of changing plate thickness on initiation and propagation, since from currently inferred values of fracture toughness the ratio would be expected to be already small for crack propagation even in 1 in. material, whereas it is clearly much larger, even in the current case of 3 in. thick plate, at crack starting. It is certain that this effect of easier crack initiation in thicker material (without change of behaviour in the Charpy test) should be further investigated, both because of its economic implication, and to achieve better understanding. For instance, if plane strain initiation conditions have already been closely approached at 3 in. thickness, then an increase of thickness to 5 in. would not have as large an effect as the change from 1 in. to 3 in.

The premature fractures between test plates and end attachment welds are also illustrative of other conditions than in the adopted configuration for low stress fracture associated with welded joints, and these also deserve further investigation. The vulnerability associated with planar defects at the fusion line between parent and weld metal appears especially important, not least because the region of lowest notch ductility in the joint is suspected as being just within the parent material at this point.

Conclusions

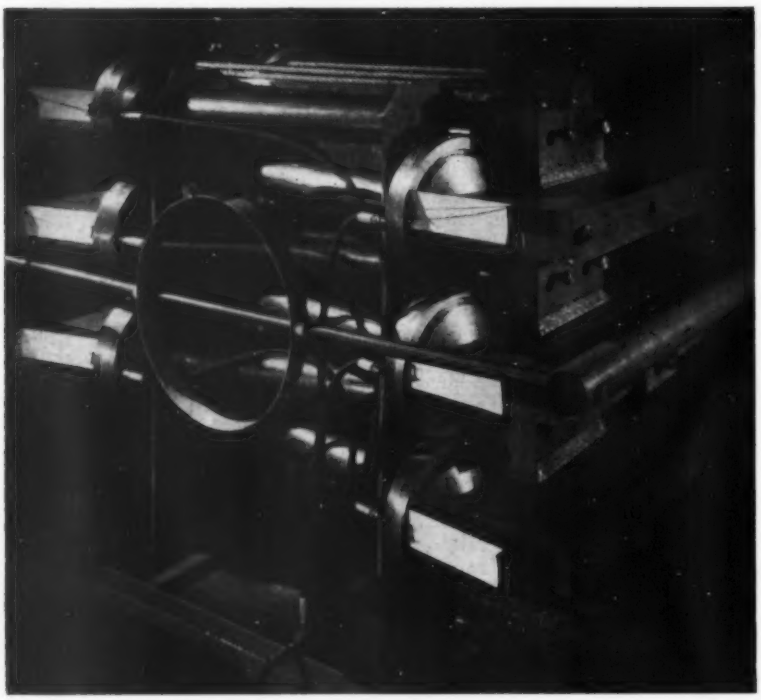
(1) Artificial sawcut defects of approximately equal areas in manually, longitudinally welded 1 in. and 3 in. thick test plates of silicon killed and normalised low-carbon steel of comparable Charpy V-notch properties in the two thicknesses, give rise to similar stresses and extensions to fracture in the as-welded condition only when the notch in the thicker material is confined to the middle third of plate thickness.

(2) When the notches in the thicker material are placed close to the plate surfaces the stresses and extensions to fracture are smaller than in the thinner material.

(3) On the above two bases of comparison plastic extensions to fracture in 3 in. thick plates tend to be smaller than for 1 in. plates, both with furnace stress-relieved specimens, and for secondary fractures re-initiated after the occurrence of low stress short fractures in as-welded specimens. Nevertheless, all the 3 in. thick furnace stress-relieved specimens that were tested, in the temperature range down to 45°C. below the fracture appearance transition temperature of the parent material, exhibited at least yield point strength and some general plastic deformation before fracture.

(4) In association with conclusions (1) and (2) a residual stress survey for an as-welded 3 in. thick manually butt-welded specimen indicates that longitudinal tensile residual stress has been substantially relieved at the root of the weld near mid-thickness by the addition of subsequent runs of weld metal.

(5) Several extraneous low stress fractures were observed at the transversely loaded end attachment butt welds between specimens and the loading equipment. These fractures were initiated at planar weld defects at the interface between parent and weld metal, and propagated the full weld length near one plate surface before travelling through the remaining plate thickness. Although thought to have been facilitated by recurrent thermal cycles from remaking these welds with successive test plates, they are regarded as



11—*B.W.R.A. 2,000-ton test rig*

significant examples of low stress fractures such as could occur in industrial structures.

APPENDIX

The 2,000-ton Testing Equipment

This equipment is closely similar in conception to the 600-ton test rig previously described,[7] but embodies 12 instead of 4 of the hydraulic loading capsules described in that report. However, the end attachments whereby the load is transferred from the capsules to the test plate, differ fundamentally in design from those formerly used. The different conditions catered for are firstly, a much higher density of capsule packing to accommodate the capsules within the same test plate width, and secondly, a simplification arising from the inevitably much more uniform loading distribution across the test plate width, through having more capsules. Thus, the capsule axes are slightly staggered as shown in Fig. 11, although the loss of load from the staggering is less than 1%, and the end attachment web member is relatively lighter.

The design conditions for the equipment, and notably the end attachment members, permitted conventionally determined stresses up to yield point, leaving a margin in the possibility of appreciable local plastic deformation. In order to meet this condition the end attachments were fabricated from boiler quality plate by welding and were furnace stress-relieved. In fact the design proved to be inadequate on first test, since brittle failures occurred simultaneously at both end attachments at a load of 82% of the design value. The premature failure was traced to occurrence of general yielding at the relatively unsupported end in the top right of Fig. 11, and the additional small web members there shown were added at the time of repair. In addition to stress relief following this repair the whole end attachments were normalised and water quenched to stress-relieving temperature. Since this event no further difficulties were experienced and fracture loads have been subsequently raised to a maximum of 2,250 tons.

The first arrangements provided to absorb energy at fracture, embodying 4 separate loops of wire rope of $\frac{5}{8}$ in. dia. were unsatisfactory. The wire ropes stored too much energy instead of dissipating it, as a result of which recoil damage occurred. They also stretched in each test, and eventually parted. The system with which they were replaced is shown in Fig. 11 and embodies 4 steel bars of $1\frac{1}{2}$ in. dia., each with end nuts securing expendable lengths of steel tube. These tubes collapse plastically into convolutions when fracture occurs, and a sufficient proportion of the stored energy is thereby absorbed.

The arrangements for autographic recording of load and extension are similar to those previously described. One of the pair of strain-gauged rings for registering plate extension is visible in Fig. 11.

Acknowledgments

The author is glad to acknowledge many sources of support for this work. Both Dr. H. G. Taylor and Dr. R. Weck, as successive Directors of Research, showed implicit faith in the feasibility of the project, and gave much encouragement and helpful advice. The Chairman, Dr. L. E. Benson, and all members of the B.7 Committee made themselves responsible for financial support as well as for the useful advice, discussion and encouragement that they were otherwise able to give. Through Dr. H. Harris, it was arranged that the testing equipment should be manufactured and donated by Babcock and Wilcox Ltd. The initial supply of thick steel plate for the project was made, selected, extensively tested, and donated by Colvilles Ltd., and this was arranged by Mr. W. Barr. All stages of developing the testing equipment to beyond rated capacity and of testing were managed by the author's colleague Mr. B. A. Wakefield, and the planning and execution of all the test plate welding, as well as the heavy equipment repair, were supervised by Mr. E. O. Lawrence. Essential help from other colleagues is also acknowledged.

It is nevertheless important to record that the opinions expressed in the report are the sole responsibility of the author.

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B.W.R.A. REPORT

The Fatigue Strength of Butt Joints in H15 Alloy Welded with Cusil 73

By W. O. Dinsdale,
G.I.MECH.E.,
and R. P. Newman,
A.M.I.MECH.E.

The report describes the results obtained from fourteen series of fatigue tests carried out on ¼ in. thick H15 alloy specimens. Two forms of material were used; HS15, unclad, and HC15, clad with 99·5% pure aluminium. These were tested as plain sheet, when the unclad form gave approximately twice the strength of HC15 at 3×10^6 cycles. Specimens of each form containing transverse butt welds were also tested. A comparison between argonarc welding and self-adjusting arc welding favours the former, because of better reinforcement shape, and with each process HS15 retains slight superiority over HC15. The influence of artificial ageing at 200°C. for 2 hours, can produce reductions of strength of the order of 20%. On the other hand an improvement of strength may be obtained, in the case of HS15, by dressing off the weld reinforcement, although there is a critical dependence on absence of weld defects.

Introduction

In a previous investigation[1] the static tensile properties of butt and fillet welded joints in H15 alloy, made with Cusil 73 filler wire, were studied. The joint efficiencies of butt-welds in HC15 WP and HS15 WP made by mechanised argonarc and self-adjusting arc processes were determined for a range of thicknesses, and tests were carried out to evaluate the influence of post-weld ageing treatments, including full post-weld heat-treatment.

To complete this study of the welding of a high-strength aluminium alloy, fatigue tests of similar butt-welded specimens have now been carried out. The two welding processes and the two forms of material mentioned above have been included in the programme, but only one thickness of sheet, ¼ in., has been used. The type of specimen and the general conditions of testing were such to permit a comparison with the fatigue performance of welded, medium-strength aluminium alloys.[2]

Materials

Both the clad and unclad forms of the alloy, HC15 and HS15 respectively, were used. The specimens were taken from ¼ in. thick sheets in the fully heat-treated condition (WP). Chemical compositions and mechanical properties are given in Table I. The filler wire used throughout was Cusil 73 (Table I).

Welding Technique and Ageing Treatment

Butt-welds were made using mechanised tungsten-arc and mechanised self-adjusting arc processes. Close vee butt preparations were used and back chipping carried out before deposition of the second pass on the reverse side. Full details of the techniques are given in Table II, and the static tensile properties of the welds are shown in Table III.

Some of the specimens were artificially aged before testing, the treatment being 2 hr at 200°C.

Test Specimens and Methods of Testing

The plain material specimens had a 0·6 in. wide parallel section with 1¼ in. wide gripping portions joined by a fixed radius (1½ in.) transition. In the first series of tests failure occurred in the transition zone and was initiated at a corner of the section. For the second series of tests the corners were more heavily radiused and carefully polished longitudinally.

Welded specimens with the reinforcement left on were of 1¼ in. wide parallel form with the transverse butt-weld in the centre of length. The welded specimens with reinforcement removed had a 0·875 in. wide parallel section with 1¼ in. wide ends, joined by

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Mr. Dinsdale is a Research Officer and Mr. Newman is Chief Research Engineer of the Association.

Table I

Chemical compositions and mechanical properties of HS15 WP, HC15 WP and Cusil 73

	Composition, %							*Mechanical Properties*	
Material	*Cu*	*Si*	*Mg*	*Mn*	*Fe*	*Ti*	*Al*	*U.T.S., tons/sq.in.*	*Elong. on 2 in., %*
HS15	4·0	0·66	0·64	0·70	0·34	0·03	R	31·0	12·5
HC15*	4·03	0·65	0·63	0·69	0·35	0·04	R	28·6	12·0
Cusil 73	6·72	3·06	0·67	0·80	0·42	0·19	R	—	—

* Core analysis

Table II

Welding conditions and edge preparations

Thickness	*Type of Joint*	*Process*	*Edge Preparation*	*No. of Passes*	*Current, amp*	*Arc* volts*	*Wire Feed, in./min*	*Travel Speed, in./min*	*Remarks*
¼ in.	Butt	Mechanised tungsten-arc	90°V ⅛ in. Root face†	2	250	—	47·5	5	Back chipped before second pass
¼ in.	Butt	Mechanised self-adjusting arc	70°V ⅛ in. Root face†	2	180–185	25	170	17	Back chipped before second pass

* Measured at power source † No root gap
Argon flow—45 cu.ft/hr(Self-adjusting arc)
15 cu.ft/hr (Tungsten-arc)

a fixed (1·0 in.) transition curve. The edges were generously radiused and all the machined portion carefully polished.

The testing procedure was to determine S/N curves between endurance limits of approx. 10^5 up to 3×10^6 cycles, under conditions of axial loading with a fixed stress cycle of $f_{min}/f_{max}=0$. A 6 ton hydraulic machine was used, with testing frequencies in the range 1,500–2,000 cycles/min.

Radiography

All test plates were radiographed before cutting up into test specimens. Start and finish points were cut out, so that test pieces were free from craters. Pieces containing any major defects were also discarded.

None of the welds was entirely free from defects. The quality of the self-adjusting arc welds ranged from sparse grade "A" porosity to linear grade "B", this latter being associated with lack of fusion.

The argonarc welded plates contained much less porosity than those welded by the self-adjusting arc process, the worst being linear grade "A". Another form of defect, oxide inclusions, was shown to be present. As stated above, sections containing large areas of inclusions were not used for making specimens.

Test Results

The test results are given in Tables IV *a–n*, and shown in the S/N diagrams Figs. 1–5. Table V is a summary of the results obtained in terms of the fatigue strength values corresponding to 3×10^6 cycles.

The following nomenclature has been used to identify the various groups of specimens:

For HS15 WP

S_p—Plain material
S_t—Argonarc as-welded
S_{ta}—Argonarc, aged after welding
S_{tr}—Argonarc welded, reinforcement removed
S_{tar}—Argonarc, aged after welding, reinforcement removed
S_m—Self-adjusting arc, as-welded
S_{ma}—Self-adjusting arc, aged after welding
S_{mr}—Self-adjusting arc welded, reinforcement removed
S_{mar}—Self-adjusting arc, aged after welding, reinforcement removed

For HC15 WP

C_p—Plain material
C_t—Argonarc as-welded
C_{ta}—Argonarc, aged after welding
C_m—Self-adjusting arc, as-welded
C_{ma}—Self-adjusting arc, aged after welding

(*a*) **Plain material** (S_p and C_p)

Two series of tests were made on each of the plain materials, the specimen design being the same for each. In the first series of tests, failure almost invariably occurred in the transition zone, initiating from a corner. For the second series of tests all corners of the specimen were generously radiused and carefully polished along the length of the specimen, and although the fatigue strength was not significantly

Table III

Tensile properties of butt welds in H15 alloys

Material	*Process*	*As-welded*			*Welded and Aged 2 hr, 200°C.*		
		U.T.S., tons/sq.in.	*Elong. on 2 in., %*	*Position of Fracture*	*U.T.S., tons/sq.in.*	*Elong. on 2 in., %*	*Position of Fracture*
HS15 WP Reinforcement removed	Mechanised tungsten-arc	17·6	1·5	Weld	17·2	1·5	Weld
	Mechanised self-adjusting arc	19·4–19·6 19·5	2–3 2·5	Weld	18·7–20·5 19·5	2–3 2	Weld
HS15 WP Reinforcement intact	Mechanised tungsten-arc	18·4–19·8 19·2	1–2 1·5	Weld	19·4–20·4 19·9	2–2·5 2	Weld
	Mechanised self-adjusting arc	19·1–22·7 20·9	1–3 2	Weld	20·8–23·2 21·8	3–4 3	Weld
HC15 WP Reinforcement intact	Mechanised tungsten-arc	16·8–17·7 17·3	1·5–2 2	Weld	18·9–19·7 19·3	2–3 2·5	Weld
	Mechanised self-adjusting arc	18·5–21·2 19·8	1–3 2	Weld	18·1–21·5 19·6	2–3 2·5	Weld

Table IV

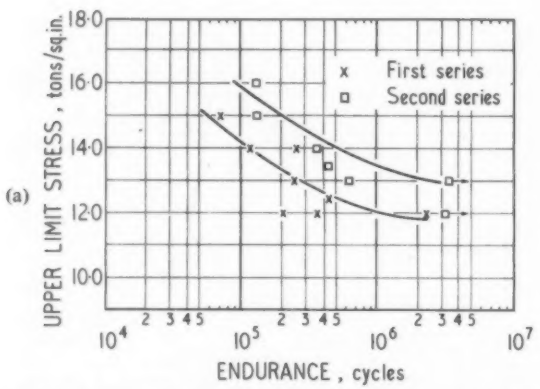
Fatigue test results

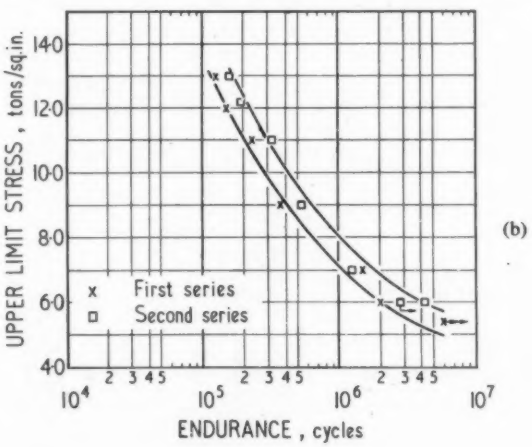
Specimen No.	Upper Limit Stress, tons/sq.in.	Cycles ×10⁶	Remarks
(a) HS15 WP plain material. Group S_p			
S_p/1	15·0	0·075	Failed from corner in test section
/2	14·0	0·129	Failed from corner in transition curve
/3	14·0	0·271	Failed from corner in transition curve
/4	13·0	0·260	Failed from corner in test section
/5	12·5	0·440	" " " " " "
/6	12·0	0·206	Failed from corner in transition curve
/7	12·0	0·372	Failed from corner in transition curve
/8	12·0	2·244	Grip failure
S_{ps}/1	16·0	0·141	Failed in test section
/2	15·0	0·143	" " " "
/3	14·0	0·383	" " " "
/4	13·5	0·435	" " " "
/5	13·0	0·645	Grip failure
/6	13·0	3·450	Unbroken
/7	12·0	3·187	"
(b) HC15 WP plain material. Group C_p			
C_p/1	13·0	0·133	Failed in transition curve
/2	12·0	0·154	" " " "
/3	11·0	0·235	" " " "
/4	9·0	0·380	" " " "
/5	7·0	1·501	Failed in test section
/6	6·0	2·029	Failed in transition curve
/7	6·0	2·022	" " " "
/8	5·5	6·000	Unbroken
C_{ps}/1	13·0	0·167	Failed in test section
/2	12·25	0·199	" " " "
/3	11·0	0·316	Failed at junction of test section and transition curve
/4	9·0	0·532	Failed at junction of test section and transition curve
/5	7·0	1·287	Failed in transition curve
/6	6·0	2·798	Unbroken
/7	6·0	4·132	Failed in test section
/8	5·5	6·185	Unbroken

Specimen No.	Upper Limit Stress, tons/sq.in.	Cycles ×10⁶	Remarks
(c) HC15 WP. Argonarc as-welded. Group C_t			
C_t/1	8·0	0·251	Failed at edge of reinforcement
/2	8·0	0·253	" " " " "
/3	7·0	0·250	Asymmetric reinforcement
/4	6·0	0·8636	Failed at edge of reinforcement
/5	6·0	0·990	" " " " "
/6	5·0	2·271	" " " " "
/7	4·0	4·076	Unbroken
/8	4·0	4·428	"
(d) HC15 WP. Argonarc, aged after welding. Group C_{ta}			
C_{ta}/1	8·0	0·139	Failed at edge of reinforcement
/2	8·0	0·176	" " " " "
/3	7·0	0·4234	" " " " "
/4	6·0	0·679	" " " " "
/5	6·0	0·972	" " " " "
/6	5·0	2·229	" " " " "
/7	4·0	3·768	Unbroken
/8	4·0	5·865	"
(e) HC15 WP. Self-adjusting arc, as-welded. Group C_m			
C_m/1	8·0	0·259	Failed at edge of reinforcement
/2	7·0	0·339	" " " " "
/3	6·0	0·393	" " " " "
/4	5·0	1·208	" " " " "
/5	4·0	3·090	Unbroken
/6	4·0	3·186	"
(f) Self-adjusting arc, aged after welding. Group C_{ma}			
C_{ma}/1	8·0	0·159	Failed at edge of reinforcement
/2	7·0	0·189	" " " " "
/3	6·0	0·439	" " " " "
/4	5·0	0·460	" " " " "
/5	4·0	1·982	" " " " "
/6	3·0	3·096	Unbroken
/7	3·0	3·154	"
(g) HS15 WP. Argonarc as-welded. Group S_t			
S_t/1	10·0	0·200	Failed at edge of reinforcement
/2	9·0	0·408	" " " " "
/3	8·0	0·598	" " " " "
/4	7·0	1·365	" " " " "
/5	6·0	4·156	Unbroken
/6	6·0	4·434	"

changed, the position of failure was shifted to the surface of the sheet in the parallel test section.

Comparing the results for the HC15 and HS15 plain specimens, (Figs. 1*a*, 1*b*) it would appear that the ratio of clad to unclad strengths decreases rapidly as the number of cycles is increased above 10^5. For 3×10^6 cycles the stress range for the unclad material is of the order of $12\frac{1}{2}$ tons/sq.in. whilst that of the





1—*S/N diagrams for* (a) *HS15 WP plain plate (group* S_p*);* (b) *HC15 WP plain plate (group* C_p*)*

Table IV—*continued*

Specimen No.	Upper Limit Stress, tons/sq.in.	Cycles $\times 10^6$	Remarks
(h) HS15 WP. Argonarc aged after welding. Group S_{ta}			
S_{ta}/1	9·0	0·222	Failed at edge of reinforcement
/2	8·0	0·213	Sharp reinforcement angle
/3	7·0	0·357	Lack of fusion
/4	7·0	0·872	Failed at edge of reinforcement
/5	6·0	2·032	,, ,, ,, ,, ,,
/6	5·0	1·739	Change in reinforcement angle
/7	5·0	3·757	Failed at edge of reinforcement
/8	5·0	4·318	Unbroken
/9	4·0	2·246	,,
(i) HS15 WP. Argonarc as-welded, reinforcement removed. Group S_{tr}			
S_{tr}/1	10·0	0·442	Failed in weld metal
/2	10·0	0·477	Failed from porosity in weld metal
/3	10·0	0·775	Failed in weld metal
/4	9·0	0·074	Lack of fusion and porosity
/5	9·0	0·426	Lack of fusion
/6	9·0	2·267	Grip failure
/7	9·0	3·772	Failed from pore breaking surface
/8	8·0	0·969	Grip failure
/9	8·0	1·007	,, ,,
/10	8·0	1·892	Failed at junction of parent plate and weld metal
/11	8·0	3·268	Unbroken
/12	7·0	2·089	Failed from pore breaking surface
(j) HS15 WP. Argonarc, aged after welding, reinforcement removed. Group S_{tar}			
S_{tar}/1	10·0	0·175	Failed in weld metal
/2	10·0	0·292	,, ,, ,, ,,
/3	9·5	0·286	,, ,, ,, ,,
/4	9·0	0·658	,, ,, ,, ,,
/5	9·0	0·221	Lack of fusion
/6	9·0	4·133	Grip failure
/7	8·0	0·058	Lack of fusion and porosity
/8	8·0	4·698	Grip failure
/9	8·0	1·683	,, ,,
/10	8·0	3·099	Unbroken
/11	7·0	5·683	,,

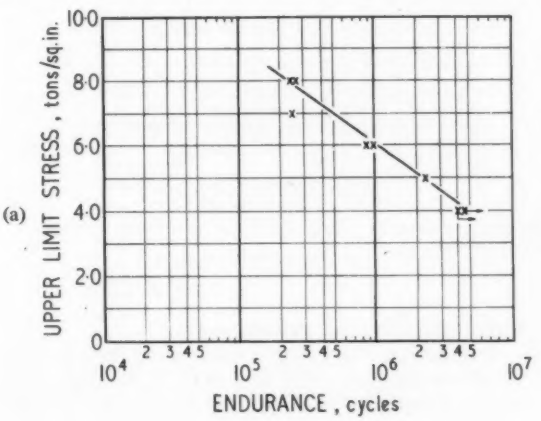
Specimen No.	Upper Limit Stress, tons/sq.in.	Cycles $\times 10^6$	Remarks
(k) HS15 WP. Self-adjusting arc, as-welded. Group S_m			
S_m/1	11·0	0·048	Failed at edge of reinforcement
/2	9·0	0·138	,, ,, ,, ,, ,,
/3	8·0	0·259	,, ,, ,, ,, ,,
/4	7·0	0·448	,, ,, ,, ,, ,,
/5	6·0	0·800	,, ,, ,, ,, ,,
/6	5·0	0·530	Uneven weld bead with 90° reinforcement angle
/7	5·0	1·328	Re-entrant weld bead with ripples
/8	5·0	3·155	Unbroken
/9	4·0	3·602	,,
(l) HS15 WP. Self-adjusting arc, aged after welding. Group S_{ma}			
S_{ma}/1	8·0	0·120	Failed at edge of reinforcement
/2	7·0	0·278	,, ,, ,, ,, ,,
/3	6·0	0·441	,, ,, ,, ,, ,,
/4	5·0	1·222	,, ,, ,, ,, ,,
/5	5·0	1·392	Grip failure
/6	4·0	3·100	Unbroken
/7	4·0	3·219	,,
(m) HS15 WP. Self-adjusting arc, as-welded, reinforcement removed. Group S_{mr}			
S_{mr}/1	11·0	0·125	Failed in weld metal
/2	10·0	0·242	,, ,, ,, ,,
/3	10·0	1·962	Grip failure
/4	9·5	0·995	Failed in weld metal
/5	9·0	1·392	Grip failure
/6	9·0	1·007	,, ,,
/7	8·0	2·052	Failed from pore breaking surface in weld metal
/8	7·0	3·186	Unbroken
/9	7·0	5·074	,,
(n) HS15 WP. Self-adjusting arc, aged after welding, reinforcement removed. Group S_{mar}			
S_{mar}/1	12·0	0·114	Failed in weld metal
/2	11·0	0·202	,, ,, ,, ,,
/3	10·0	0·379	,, ,, ,, ,,
/4	9·0	0·637	,, ,, ,, ,,
/5	9·0	0·140	Lack of fusion
/6	8·0	1·153	Failed in weld metal
/7	8·0	1·632	Grip failure
/8	8·0	2·036	,, ,,
/9	7·0	3·125	Unbroken
/10	7·0	5·026	,,

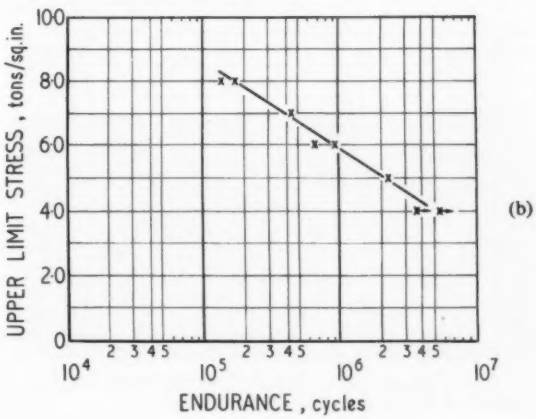
clad material is 6·0 tons/sq.in. Therefore cladding results in a reduction of fatigue strength of 50% at 3×10^6 cycles.

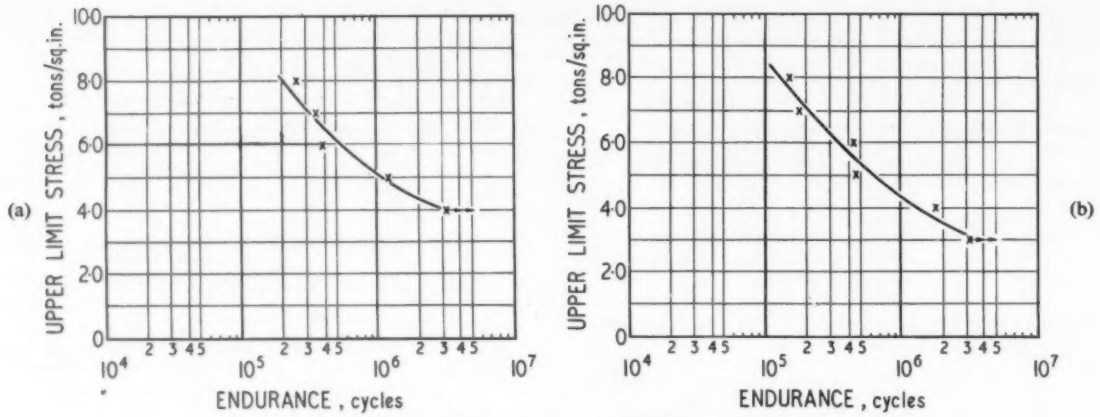
(*b*) **HC15 argonarc as-welded (C_t)**

All specimens in this group failed from the edge of the reinforcement. In most cases the weld metal had overlapped the cladding without fusing, failure starting from underneath this overlap, as shown in Fig. 6.

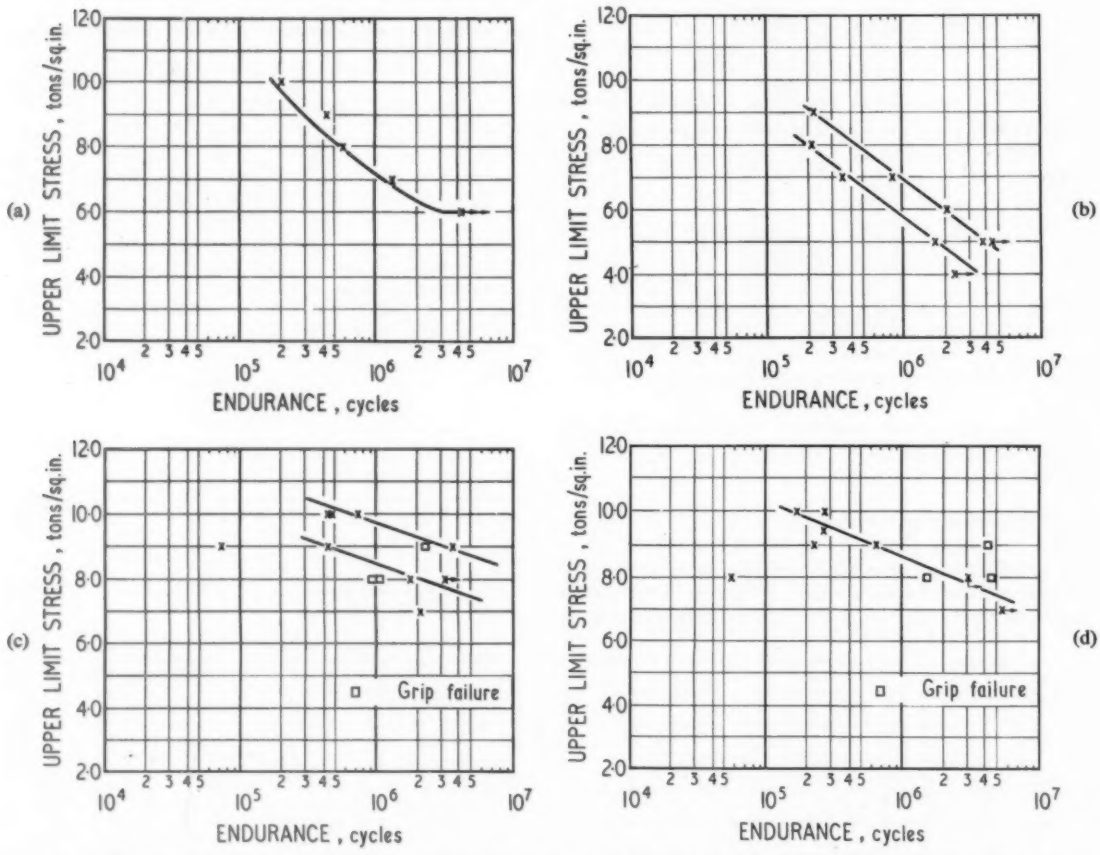
2—*S/N diagrams* (a) *Tig welded HC15 WP* (*group* C_t); (b) *aged after welding* (*group* C_{ta})







3—*S/N diagrams for* (a) *Mig welded HC15 WP (group* C_m*);* (b) *aged after welding (group* C_{ma}*)*



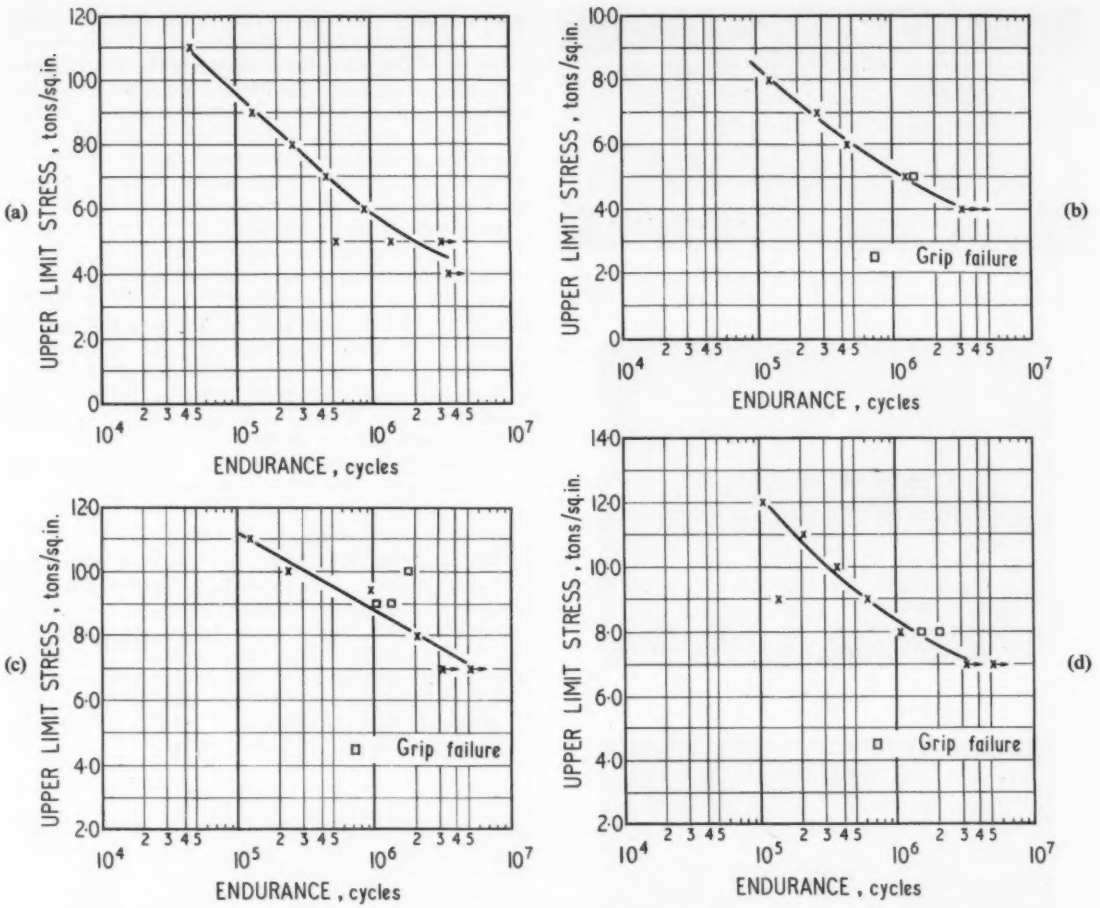
4—*S/N diagrams for* (a) *Tig welded HS15 WP (group* S_t*);* (b) *aged after welding (group* S_{ta}*);* (c) *reinforcement removed (group* S_{tr}*);* (d) *aged after welding, reinforcement removed (group* S_{tr}*)*

Specimen No. $C_t/3$ tested at 7·0 tons/sq.in. had an asymmetric reinforcement with a more severe angle at one side giving a somewhat lower life.

As shown in Fig. 2*a* the fatigue strength for 3×10^6 cycles is approximately $4\frac{3}{4}$ tons/sq.in.

(c) HC15 argonarc aged after welding (C_{ta})

Specimens in this group failed in a similar manner to the as-welded specimens, that is from the edge of the reinforcement. It was noted that as soon as the crack



5—*S/N diagrams for* (a) *Mig welded HS15 WP (group* S_m*);* (b) *aged after welding (group* S_{ma}*);* (c) *reinforcement removed (group* S_{mr}*);* (d) *aged after welding, reinforcement removed (group* S_{mar}*)*

Table V

Summary of results

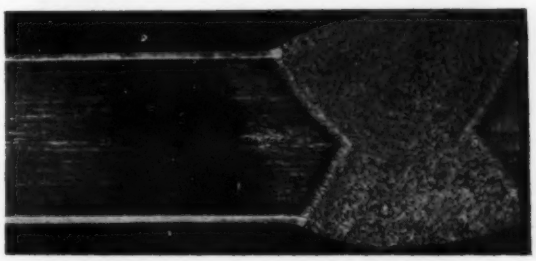
Test Group	*Specimen Details*	*Fatigue Strength at 3×10^6 cycles (0/+) tons/sq.in.*
	HS15 WP	
S_p	Plain sheet	12½
S_t	Tungsten-arc, as-welded	6
S_{ta}	Tungsten-arc, aged after welding	5½
S_{tr}	Tungsten-arc, reinforcement removed	8½
S_{tar}	Tungsten-arc, aged, reinforcement removed	7¾
S_m	Self-adjusting arc, as-welded	4½
S_{ma}	Self-adjusting arc, aged after welding	4
S_{mr}	Self-adjusting arc, reinforcement removed	7¾
S_{mar}	Self-adjusting arc, aged, reinforcement removed	7
	HC15 WP	
C_p	Plain sheet	6
C_t	Tungsten-arc, as-welded	4¾
C_{ta}	Tungsten-arc, aged after welding	4½
C_m	Self-adjusting arc, as-welded	4
C_{ma}	Self-adjusting arc, aged after welding	3

reached the weld metal the specimen failed in a brittle manner.

The fatigue strength for 3×10^6 cycles is 4½ tons/sq.in., the S/N diagram being shown in Fig. 2*b*.

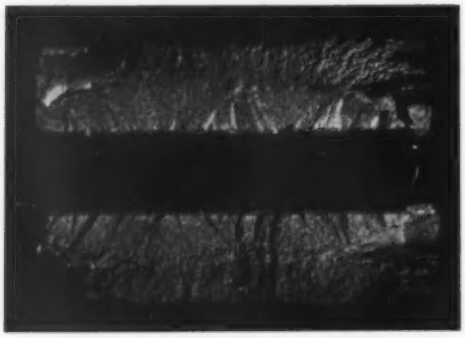
(*d*) **HC15 self-adjusting arc as-welded** (C_m)

Overlap of the cladding by the weld metal was also noted in these specimens (Fig. 7) and fatigue failure

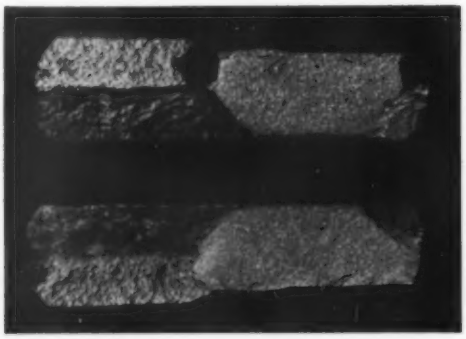


6—*Macrosection of argonarc welded HC15 showing failure from overlap (group* C_t*)* ×5½

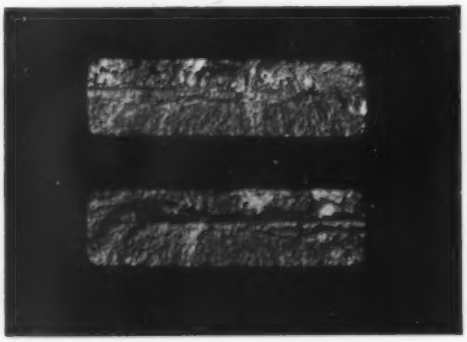
7—*Macrosection of self-adjusting arc welded HC15 showing weld metal overlapping cladding (group C_m)* ×4½



8—*Fracture face of self-adjusting arc welded HC15 (group C_{ma})*



9—*Typical failure of argonarc welded HS15 (group S_t) also showing lack of fusion*



10—*Fracture face of argonarc welded HS15 with reinforcement removed (group S_{tar}) showing failure from defect*

was initiated at the edge of the reinforcement, underneath the overlap. The fatigue strength for 3×10^6 cycles was 4·0 tons/sq.in. as shown in the S/N diagram Fig. 3*a*. In comparison with the argonarc as-welded specimens (group C_t) the strength is ¾ ton/sq.in. lower. This is possibly due to a difference in reinforcement shape, the self-adjusting arc welds being rougher in appearance than the argonarc welds. Brittle failure of the specimen was again observed as soon as the crack propagated into the weld metal.

(*e*) HC15 self-adjusting arc aged after welding (C_{ma})

The S/N diagram for this series is shown in Fig. 3*b*; whilst it is of the same general shape as that for the 'as-welded' specimens (group C_m) the strength for 3×10^6 cycles is 1·0 tons/sq.in. lower, *i.e.* 3·0 tons/sq.in. This also compares unfavourably with the results for aged argonarc welds (group C_{ta}), showing a reduction of the order of 30%.

The mode of failure was the same as for the previous groups and a typical failure is shown in Fig. 8.

(*f*) HS15 argonarc as-welded (S_t)

The fatigue strength, for 3×10^6 cycles, obtained for this test series was 6½ tons/sq.in. The failures all initiated at the edge of the reinforcement and propagated through the parent plate. In specimens No. $S_t/3$ and $S_t/4$ the fatigue area was smaller than on the other specimens, the failure becoming brittle as soon as the crack reached the weld metal. The fracture face of specimen No. $S_t/4$ is shown in Fig. 9; this also shows some evidence of lack of fusion.

(*g*) HS15 argonarc aged after welding (S_{ta})

In this group, scatter was more pronounced than with the other series of tests in which the weld reinforcement was left on (Fig. 4*b*). Examination of the specimens showed that those on the lower side of the scatter band exhibited features which could account for the shorter life, notably the incidence of local or general variations in reinforcement shape of a kind that would increase the stress concentration effect of the weld bead. The upper limit value of 5½ tons/sq.in. for 3×10^6 cycles, is 1·0 tons/sq.in. lower than the strength figure obtained for the as-welded material.

(*h*) HS15 argonarc as-welded reinforcement removed (S_{tr})

With the reinforcement machined off, failure in this group of specimens was located either in the weld metal or in the grips. Porosity breaking the surface and defects in the weld metal became of major importance as sites of failure. The specimen tested at 9·0 tons/sq.in. ($S_{tr}/4$) which failed after 74,000 cycles contained a lack of fusion defect with some porosity. Specimens No. $S_{tr}/7$ and No. $S_{tr}/12$, which broke after 3,772,000 and 2,089,000 cycles respectively, both failed from pores which broke the surface of the weld metal. It was particularly noticeable that the weld metal only sustained a small fatigue crack before failing in a brittle manner.

Three specimens failed in the grips—one of them giving a result at the upper limit of the scatter band, and two near the lower limit of the band. A strength of approx. 8½ tons/sq.in. at 3×10^6 cycles is indicated (Fig. 4*c*).

(*i*) HS15 argonarc, aged after welding, reinforcement removed (S_{tar})

This series again shows the lower fatigue strength obtained with aged specimens, $7\frac{3}{4}$ tons/sq.in. as opposed to $8\frac{1}{2}$ tons/sq.in. as-welded. One specimen ($S_{tar}/7$), tested at 8·0 tons/sq.in., failed after 58,000 cycles, the failure being caused by lack of fusion associated with porosity, the crack starting from the defect (Fig. 10). Specimen $S_{tar}/5$, which failed after 221,000 cycles at 9·0 tons/sq.in., also contained a short length in which there was lack of fusion.

(*j*) HS15 self-adjusting arc, as-welded (S_m)

Two specimens from this group exhibited reduced life, both at 5·0 tons/sq.in. Specimen $S_m/6$ had an uneven weld bead making an angle of almost 90° with the parent material and failed after only 530,000 cycles. The other specimen, $S_m/7$, which failed after 1,328,000 cycles, had a small section of re-entrant weld bead. This, in conjunction with a ripple in the weld metal, undoubtedly enhanced the stress concentration at the edge of the weld.

The other specimens in the series failed in a brittle manner when the crack, initiated at the reinforcement edge, reached the weld metal. The fatigue strength, for 3×10^6 cycles, was $4\frac{3}{4}$ tons/sq.in.

(*k*) HS15 self-adjusting arc, aged after welding (S_{ma})

In this series, one specimen, $S_{ma}/5$, failed in the grips. The test point is identified on the S/N diagram, Fig. 5*b*, and it will be seen that, in terms of life to failure, the result is comparable with the other tests. The remainder of the broken specimens failed in a brittle manner as soon as the crack, which initiated at the reinforcement edge, propagated into the weld metal. The fatigue strength 4·0 tons/sq.in. is lower than that for the as-welded specimens (group S_m) by $\frac{3}{4}$ ton/sq.in.

(*l*) HS15 self-adjusting arc, as-welded, reinforcement removed (S_{mr})

In this group with the weld reinforcement removed, the majority of failures were located in the weld metal, which sustained only a small fatigue crack before brittle failure occurred. A typical specimen is shown in Fig. 11.

Three specimens fractured in the grips, two of them being comparable in life to the welded specimens. The third specimen, tested at 10·0 tons/sq.in. had a considerably longer life.

11—*Typical failure of self-adjusting arc welded HS15 with reinforcement removed (group S_{mr}) showing small fatigue area and brittle fracture*

The fatigue strength achieved by this group was $7\frac{3}{4}$ tons/sq.in., the S/N curve being shown in Fig. 5*c*, in which the grip failures are identified.

(*m*) HS15 self-adjusting arc, aged after welding, reinforcement removed (S_{mar})

The majority of failures in this group also initiated in the weld metal, which again exhibited the small fatigue area before brittle failure. Specimen No. $S_{mar}/5$ contained lack of fusion between runs giving rise to fracture after 140,000 cycles. Two specimens failed in the grips at 8·0 tons/sq.in.

The fatigue strength of this group of specimens was $\frac{3}{4}$ ton/sq.in. lower than that of the as-welded group S_{mr}, 7·0 tons/sq.in. as opposed to $7\frac{3}{4}$ tons/sq.in.

Discussion

The fourteen groups of tests carried out permit a number of comparisons to be made between material forms, processes and so on, and for clarity these are dealt with under sub-headings.

Influence of material form

Tested as unwelded sheet the two material forms, clad and unclad, give very different fatigue strength values at high endurances. At 3×10^6 cycles the related strengths are 6 and $12\frac{1}{2}$ tons/sq.in. respectively. On the other hand the slopes of the S/N curves are dissimilar and at low endurances the difference in fatigue performance is less marked, such that the curves probably coincide at about 10^5 cycles.

The same kind of general result for clad and unclad aluminium alloys has been reported by Forrest[3] who noted two important facts. Firstly, the large difference in strength at high endurances, attributable to the inherently lower strength of the pure aluminium cladding, is observed for normal atmospheric conditions. The results for fatigue in air can be reversed when a corrosive environment is introduced. Secondly, Forrest quotes the results of some tests of spot-welded specimens in the two material forms to show that when stress concentrations due to joint configuraton operate the fatigue performance of the clad material can equal that of the unclad material. Thus the effect of the early initiation of small cracks in the cladding is offset by influence of other severe stress raisers. Moreover, Forrest also observed that the difference in fatigue limits for the two materials in sheet form, decreases with increasing mean stress. This effect was not studied in the present work but is commensurate with the different slopes to the S/N curves.

It was also shown in this investigation that stress concentrations associated with joint configuration tend to equalise the performances of the materials. With the smaller stress concentration developed by a transverse butt-weld with the reinforcement left on, the strength limits at 3×10^6 cycles were 4–6 tons/sq.in. for HS15 joints and 3–$4\frac{3}{4}$ tons/sq.in. for HC15 joints. Taking average values for non-aged specimens, the influence of the cladding is thus to produce a 50% reduction of plain sheet strength and a 19% reduction of joint stength.

It is of interest to note that the range of fatigue limits 4–6 tons/sq.in. for the HS15 joints, if adjusted

to the stress levels relating to 2×10^6 cycles, say 4½–6½ tons/sq.in., show virtually no increase over the strength values determined for NP5/6 and HE30 butt joints[2] at the 2×10^6 cycle endurance limit.

Comparison of welding processes

With each of the processes the traverse of the welding head was mechanised. This would presumably tend to reduce variations in weld profile and a comparison of the processes on the basis of these tests should not be taken as a perfectly general assessment of merit. In fact, the tungsten-arc welds showed some superiority over self-adjusting arc welds, the respective fatigue limit ranges, for 3×10^6 cycles, being 4½–6 tons/sq.in. and 3–4¾ tons/sq.in. In so far as could be observed this difference was due to a rather better finish at the edge of the weld obtained with the tungsten-arc process. Even so, scatter was not entirely absent and in some tests reductions of life due to variation in reinforcement shape were obtained and were associated with both processes.

Tests of welded joints in medium strength alloys[2] have also shown tungsten-arc welding to have an apparent superiority, but further work in this field has indicated that Mig welds can give equal performance if steps are taken to control what appears otherwise to be an intrinsically less favourable reinforcement shape.

The influence of artificial ageing

The ageing treatment used, 2 hr at 200°C., is one previously employed in the welding of H15 alloy.[1] It has been shown, however, that for material ¼ in. thick, this treatment does not have the same beneficial effect on static tensile properties as it does with thin material in which the heat-affected zone is more extensive. Under conditions of fatigue stressing, the artificial ageing treatment of ¼ in. thick welded specimens tended to produce lower strengths. This applied equally to butt-welds having the reinforcement both left on and machined off, when different modes of failure are observed (*i.e.* in the heat-affected zone and the weld metal respectively).

The manner in which artificial ageing affects fatigue properties has not been studied in the present work, but Tomlinson and Wood[4] have found the same influence and Baker[5] has suggested that grain stiffening due to precipitation during ageing increases the notch sensitivity of the heat-affected zone. A current investigation of welded H30 alloy has similarly shown a reduction of fatigue strength with artificial ageing, the loss being of the order of 15%. In H15 alloy the reductions are in the range 5–8% for tungsten-arc welds and 15–25% for self-adjusting arc welds.

Removal of weld reinforcement (HS15 welds only)

It has been observed in investigations of medium strength alloys[2,4] that the removal of reinforcement from butt-welds does not produce a significant increase of fatigue strength. In such specimens failure is almost always initiated in the weld metal and the incidence of defects assumes greater importance. In particular it has been noted that pores exposed on the surface by the machining act as crack initiation points and it may be conjectured that they become preferred sites for failure because of their exposure to atmosphere.

In the present work the highest strengths obtained, ranging from 7 to 8½ tons/sq.in. at 3×10^6 cycles, were associated with the dressed HS15 welds. Failure of weld metal occurred consistently among those specimens that did not fracture in the grips and these failures started from the surface of the weld. The argonarc welds, with strengths of 7¾ and 8½ tons/sq.in. were slightly superior to the self-adjusting arc welds which had corresponding strengths of 7 and 7¾ tons/sq.in. (where the first value is for aged welds). This difference can, perhaps, be attributed to the somewhat greater incidence of porosity in the latter welds. The occurrence of more severe defects, such as lack of fusion, is certainly detrimental.

The brittle failure of the weld metal, as the mode of final rupture, was clearly demonstrated in these tests, failure of this kind occurring when only very small fatigue crack areas had been formed. The apparent notch-sensitivity of the weld metal can perhaps be linked with the reduced ductility values obtained in static testing when weld failure is involved (2–3% on a 2 in. gauge length, compared with 10–15% for the unwelded sheet).

Conclusions

The following conclusions relate to the fatigue performance of HC15 and HS15 specimens, ¼ in. thick, tested under axial, pulsating tension loading, strengths being expressed as the stress range corresponding to 3×10^6 cycles.

(1) Under air-fatigue conditions the presence of aluminium cladding reduces the fatigue strength of plain sheet by 50%, *i.e.* from 12½ to 6 tons/sq.in. In the presence of stress concentrations associated with transverse butt welds, the influence of the cladding is diminished; a reduction of strength of about 19% for welds in clad material was observed.

(2) The strengths of as-welded transverse butt joints depend to an important degree on weld profile. Argonarc welds gave strengths between 4¾ and 6 tons/sq.in. and self-adjusting arc welds between 4 and 4¾ tons/sq.in., lower values relating to the clad material. The reduction of plain sheet strength due to the presence of butt-welds is thus of the order of 50–60% in unclad HS15 alloy and 30–40% in clad HC15 alloy.

(3) Artificial ageing at 200°C. for 2 hr does not improve fatigue properties and may result in some loss of strength.

(4) Improvement of fatigue strength can be secured by machining off the weld reinforcement of HS15 welds, but depends upon the condition of the weld metal in respect of defects. Porosity is most commonly found and may be more detrimental when exposed on the dressed surface.

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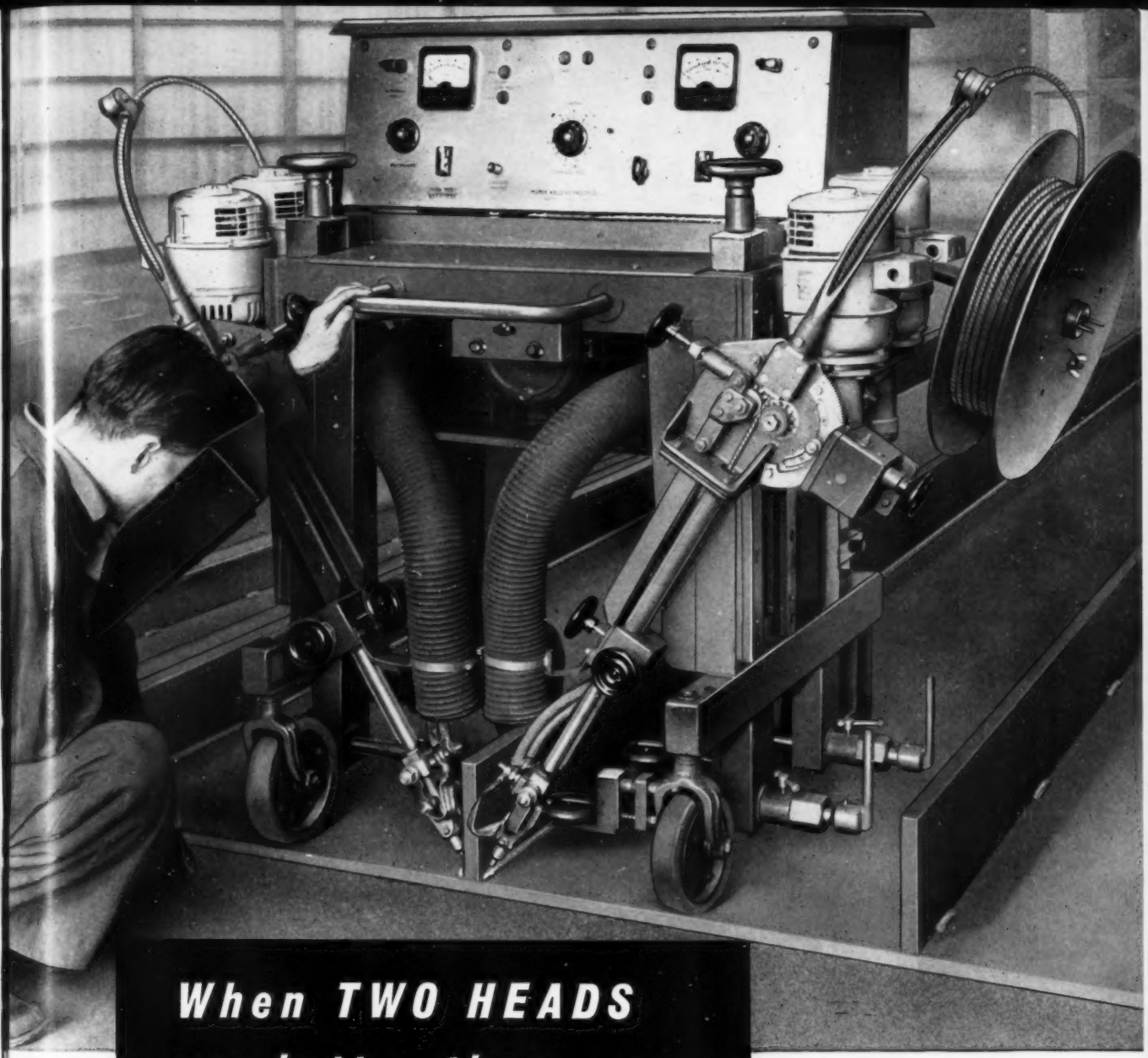

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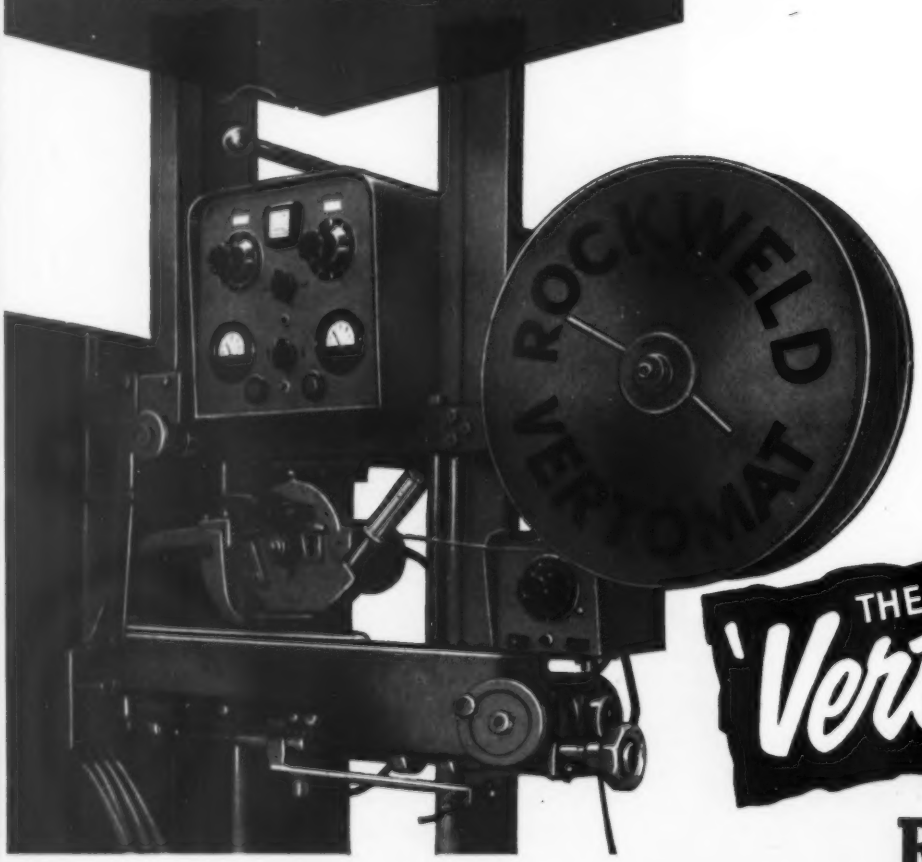

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CRACKING OF OXIDE FILMS IN SPOT WELDING

The pattern in which the current flows through a weld is influenced by the way the oxide film on the surfaces of the work pieces breaks down under the force applied by the electrodes. This note describes how the cracking of the oxide may be influenced by the surface roughness and also by the mechanical strength of the oxide and of the metal.

J. B. P. Williamson, PH.D., A.M.INST.W., *and J. H. Tripp*, B.SC.

THE way in which the oxide films on metals break down when a force is applied to the surface is of major importance in welding. This has been recognised as a fundamental process in pressure welding for many years and although its significance in resistance welding is well known it may not be so widely appreciated. In fact, the manner in which the oxide breaks down determines the initial pattern of current flow through the weld and can have a marked influence on the temperature distribution created in the nugget. The techniques employed in pressure welding usually aim to increase the degree of oxide breakdown by encouraging tangential slip at the interface or by stretching the surfaces so that the brittle oxides pull apart. In spot welding the metal surfaces are pressed together without any increase in their area and with little or no tangential slip, and at first sight it is difficult to see why the oxide should break down at all. Particularly so since it has recently been reported[1] that 4% strain is necessary to rupture the oxide on mild steel. Nevertheless it is clear that considerable breakdown does occur before the current is applied—as can easily be demonstrated by measuring the resistance across the interface between two metal sheets while the force pressing them together is increased.

During an investigation of the behaviour of oxide on mild steel we have repeated the direct determination of the strain necessary to cause rupture. The experiment was basically similar to that already reported,[1] but instead of immersing the specimen in sodium chloride solution (which might attack the oxide and thus affect the results) it was immersed in N/10 H_2SO_4 and a potentiostat was arranged to maintain the voltage between the steel specimen and a platinum probe in the liquid at a value that would ensure that a thin film of oxide existed on the steel. The potentiostat[2] measures the potential difference across the oxide film on a metal and passes a current through the oxide so as to maintain this potential difference, and thus the thickness of the oxide, constant. If a small region of the surface becomes bare (as will happen if the oxide cracks) the potential between the platinum probe and the work piece will drop, and the potentiostat will immediately supply sufficient current to rebuild the oxide and restore the potential difference. After the oxide film has been mended the current will return to its original low value.

The specimen was mounted on a tensometer and the oxide was completely removed (using the potentiostat) and a fresh oxide layer about 100Å thick was grown. In this way a uniform film could be tested and the effects of the unknown residual strains in the original film caused by the previous handling of the specimen could be avoided. The specimen was then stretched in simple tension, and the strain at which the oxide began to crack was detected using an oscilloscope to monitor the current supplied by the potentiometer.

The first cracks were observed when the strain was about 0·1–0·2%. Smaller values of strain could not be measured reliably in the apparatus. These cracks were sealed with new oxide in about a fifth of a second. As the strain was increased cracking continued and became very frequent at about 4% strain; this coincided with the start of necking in the specimen and may have been the phenomenon observed in the earlier experiments. This suggests that the value of 4% indicated by the earlier experiments for the strain in a metal necessary to rupture an oxide on it is too high: the oxide on mild steel cracks when the strain in the underlying metal is about 0·2%. This does not imply that the strain in the *oxide* on cracking is necessarily less than 0·2%: this may be the value at which the metal deforms by slip, thus causing very high strains to appear in the oxide layer at the end of the slip bands, and it may be these local strains which initiate the cracks. It is not clear at present whether the oxide on steel cracks because the bulk strain reaches the ultimate breaking strain of the oxide or because it reaches the elastic limit of the metal, thus creating slip bands which rupture the oxide.

However, because normal surfaces are very rough on a microscopic scale, intense local stresses are set up when individual asperities on one metal are crushed against the surface of the other. A rough idea of the strain that can be created in a surface film in this way can be obtained by considering the change in surface area that will be produced if an asperity is crushed flat—or if it is driven into a flat surface, as is more likely since in general the 'hills' on metal surfaces are more work-hardened than the flatter areas. Figure 1 shows the profile of a smooth surface (about twenty micro-inches centre-line-average roughness) which was produced by grit-blasting with silicon carbide: there are no hills with slopes greater than 5°. Examination of sev-

eral profiles (of which Fig. 1 is typical) showed that the steepest sided asperities likely to be found on such a surface have slopes of about 3 – 5°. The strain in the metal surface that would be caused if these were crushed flat can easily be shown to be about 0·2–0·4%. (Since the slope is so small the exact topography of the asperity is not important and it is sufficient to regard it as a simple cone, or as a dome—the same result is obtained from both models.) Thus the aspirities act as stress-raisers and, on all but the smoothest surfaces, create local strains in the metal surface sufficient to cause the oxide to rupture and allow the welding current to flow.

In normal spot welding the work pieces are stressed elastically: in particular the macroscopic stresses at the welding interface are well below the yield point. If the interface were flat it would not be possible to achieve even the low value of 0·2% strain in the metal, which these experiments indicate is necessary to rupture the oxide, without first producing gross plastic yielding in the work pieces near the electrodes.

Manuscript received 4th May, 1961.
The authors are at Tube Investments Research Laboratories, Cambridge.

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LETTER TO THE EDITOR

Brittle fracture strength of welded steel plates

In Appendix II of my paper on this subject (*BWJ*, May 1961, p. 275) Mr. P. Whitaker reports further determinations of McQuaid-Ehn grain sizes for each of the five steels whose brittle fracture properties have been studied by the Admiralty Advisory Committee on Structural Steel and British Welding Research Association.

By courtesy of Mr. G. Burns, Secretary to the Admiralty Committee, I am now able to present the collected data for the steels from four laboratories, including that of Mr. Whitaker, as follows:

Steel	*McQuaid-Ehn Grain Sizes*			
P	5	1–2	2–3	1–4–6
Q	4–5	4–5		1–1·5–4
R	8	6–7		5–7–8
S	7	5–6	6–7	3–6–8
T	8	6–7		4–7–8

It will be seen that the results for the normalised steels *R*, *S*, and *T* are consistent, and this disposes of doubts concerning the reproducibility of testing techniques. Mr. Whitaker's comment on variability of results for the as-rolled, semi-killed steels *P* amd *Q*, is supported, as these are seen to possess larger variations. Such may, therefore, by a typical property of as-rolled steels when extensively examined from different sampling positions.

A. A. WELLS

British Welding Research Association
Abington, Cambridge.

BOOK REVIEW

B. BRESLER and T. Y. LIN: "*Design of Steel Structures*", New York, 1960, John Wiley & Sons Inc., 710 pp. (78*s*.)

The sub-title of the book "A rational approach to the design of steel structures correlated with current design practice", taken from the context of the preface, is not explicative of the comprehensive range of its contents. In connection with steel frameworks in particular, with which the book is concerned, the word "rational" has a connotation, in this country at least, that has little to do with what is normally thought of as "current design practice". In fact, the authors set out, discursively or in detail, to record design methods and techniques quite generally, dealing with elastic problems as well as with plastic design. Correlation with practice there certainly is; the treatment of design is intimately linked with specification requirements and the detail work of design for fabrication is extensively covered. In effect, the result is an informed technical commentary on the business of creating structures, taking into account the impact or the potentialities of the results of research.

It is the declared aim of the authors to provide a book for civil engineering courses. With this in mind they have arranged their material to permit "elementary" or "advanced" study. There can be little doubt, however, that they would prefer to see the whole book taken in continuity rather than given a dual purpose character. The comment is not altogether superfluous. Many concerned with the elevation of design teaching to an advanced level see the need for sophistication of the code-of-practice approach, for example in relating fabrication practice to resultant, and often non-specification, properties of materials. Much of the subject matter of the book that gets towards this aim is to be found in the "elementary" chapters!

The examination of design problems in tension and compression members and in beams and girders is particularly well detailed, although the examples, both worked and set, naturally involve American specifications in regard to standard rolled sections, design criteria, and constants and quality requirements. Nonetheless these examples frequently help to illustrate more of real practice than is usually found in similar textbooks. In the extension, in the last three chapters, to the design of buildings and bridges and the use of light-gauge members, the treatment is necessarily more descriptive than analytical, but with adequate references for further study. It is, however, an interesting feature of the book that the structural design sections are preceded by three chapters on riveted, bolted and pinned, and welded connections, these being part of the suggested elementary course. The result is not unharmonious because the strength and behaviour of connections is constantly reiterated elsewhere as part and parcel of design process as a whole.

In regard to welding fabrication, the authors start at the beginning with the art itself, and might have usefully expanded a little on fusion welding techniques at the expense of what are little more than passing references to gas welding and resistance welding, since the latter have virtually to be abandoned in following considerations of structural joint design and strength. Metallurgy and materials are briefly, but pertinently, introduced in a section dealing with quality, and brittle fracture appears with a strong association with residual stresses. This is undoubtedly justified, but no positive lead is given as to how one minimizes residual stresses, and the emphasis on this is perhaps misplaced when the context is steel frameworks. A qualification here in regard to diminished risk on lighter sections and plates would not have been inappropriate; equally it would have been more realistic to advise that the minimization of notches and the selection of material for heavier constructions assume a higher order of concern when stress relieving is impracticable. The design of joints from the viewpoint of static stressing is adequately presented and fatigue considerations based on the AWS Specifications for Bridges are included; the further reading suggested in the references to this chapter, however, contains a good deal of dated material.

R. P. NEWMAN

NEWS and Announcements

News of the Institute and Branches
B.W.R.A. · Other Societies ·
and Industry

INSTITUTE ACTIVITIES

MEETINGS

Autumn Meeting 1961

The Autumn Meeting of the Institute this year will take the form of a Joint Symposium on Welding in Shipbuilding. It is being organised by the Institute in association with the Royal Institution of Naval Architects, the Institute of Marine Engineers, the Institution of Engineers and Shipbuilders in Scotland, and the North East Coast Institution of Engineers and Shipbuilders.

The papers will be presented at eight technical sessions during the week 30th October to 3rd November, at the Institute of Marine Engineers, Memorial Building, 76 Mark Lane, London, E.C.3, and all technical meetings will of course be open to all members of the Institute who enrol for the meeting.

Enrolment forms will be distributed in September.

The papers are too numerous to be published in the *British Welding Journal*, but summaries will appear in the October issue. The papers themselves will be preprinted and will be supplied only to those who enrol for the full Symposium.

The following is a list of the papers to be presented:

DESIGN

GENERAL

"*Some trends in the design of welded hulls*" by J. Turnbull and R. Ibison
"*Structural design of welded cargo-ships*" by H. W. Groeneveld
"*Notes on the structural design of welded ships*" by J. B. Caldwell
"*Welded hulls in shipbuilding*" by Per Stenberg
"*Welded design details*" by H. J. Adams

RESIDUAL STRESS

"*A study of residual welding stresses in restrained joints*" by Toshiro Yoshida
"*Effect of restraint on residual stress*" by Yutaka Matsuyama and Sadakazu Terao

YARDS AND CONSTRUCTION

BUILDING

"*Building of welded ships*" by T. McIver
"*Building of welded ships*" by W. R. Mellanby

HISTORY

"*Shipyard development for welding and prefabrication 1945–1960*" by J. P. Jespersen
"*Chronological summaries of shipbuilding practice in a Japanese shipyard*" by Koh Araki and Masaaki Kanayama

LAYOUT

"*Mechanisation of a platers' shop*" by C. J. Schuit
"*Shipyard layout for welded shipbuilding*" by A. Ross Belch and G. H. Parker

MATERIALS HANDLING

"*Handling of material in the hull department*" by B. Munch
"*Conveyor production system adopted in hull shops*" by Yutaka Matsuyama

MATERIALS

HIGH YIELD POINT STEELS

"*Some thoughts on the problem of welding high tensile steel*" by F. Watkinson, R. G. Baker, and H. F. Tremlett
"*Weldability of Admiralty high strength shipbuilding steels*" by W. H. Winn and L. Wortley
"*Charting some rocks and shoals on the course of using a high performance shipbuilding steel*" by C. R. Bryan and H. A. Hoffman

LIGHT ALLOYS

"*Mig welding of Al–3½%Mg alloy in shipbuilding*" by W. Santini and O. Piazzai
"*Application of welding to ship construction: with particular reference to the aluminium superstructure of TSS* Oriana" by L. Redshaw
"*Future of welded aluminium in ships*" by E. G. West and W. Muckle

WELDING AND CUTTING

PROCESSES

"*Properties of submerged-arc butt joints in mild steel*" by W. Santini and U. Girardi
"*Practical application of CO_2 welding in shipbuilding*" by A. Bohdanowicz
"*Automatic welding applied to ship construction*" by Toshio Yoshida
"*Specific defects in automatic submerged-arc welding*" by W. Gunther

PROCEDURES

"*Investigation of procedures for gunwale connections in large ships*" by Hiroshi Kihara
"*Welding procedure for doubling plates*" by Hiroshi Kihara
"*Some problems of welding procedures at a Japanese shipyard*" by Toshio Yoshida
"*Control of contractions and distortions*" by D. M. Kerr

BENDING, CUTTING, AND WELDING TECHNOLOGY

"*Effect on brittle fracture of forming by line heating method*" by Yutaka Matsuyama, Toshio Hashimoto, and Toyoo Maeda
"*Gas cutting machines*" by R. R. Sillifant
"*Welding technology in the new Gydnia dry dock*" By J. Zydowo and J. Gorski.

QUALITY CONTROL

"*Non-destructive testing of welded joints used in Naval construction*" by H. Gibbs
"*Non-destructive testing of ship welds in Holland*" by A. de. Sterke
"*The pull-out type fracture in rolled steel plates*" by Masaki Watanabe

Annual Dinner

The Annual Dinner will be held on the evening of Wednesday, 1st November, at the Connaught Rooms, Great Queen Street, London, W.C.2. On account of the very large number of overseas visitors who are expected to take part in the Symposium on Welding in Shipbuilding, Industrial Corporate Members of the Institute are advised to make very early reservations of tables. The usual reservation forms will not be

available before September, and companies are therefore urged to write to the Secretary as soon as possible indicating their probable requirements.

Presidential Address

Mr. H. West, President of the Institute for the session 1961–2, will deliver his Presidential Address at the Institute of Marine Engineers, Memorial Building, 76 Mark Lane, London, E.C.3, on the evening of Thursday, 2nd November, 1961.

Metal Spraying Conference

The Spanish Institute of Welding (Instituto de la Soldadura) announces a Third International Metal Spraying Conference to be held in Madrid from 2nd to 6th October, 1961. A provisional programme and enrolment form can be obtained from the Secretary, Instituto de la Soldadura, Serrano 144-A, Madrid 6, Spain.

1959 Autumn Meeting Discussion

The Discussion at this Joint Meeting with the Société des Ingénieurs Soudeurs, has now been translated and edited, and is available for consultation at the Institute.

On account of shortage of space it will not be published.

Council Elections 1961

In addition to the Honorary Officers, whose election unopposed was announced in the July issue, the following were elected unopposed to represent the classes shown:

Industrial Corporate Members:
E. V. Beatson; J. McLean
Companions: J. Hooper.

The following are the results of the ballot for the election of four representatives of Fellow, Members, and Associate-Members, and one representative of Associates on the Council of the Institute:

Fellows, Members, and Associate-Members: M. Birkhead; V. W. Clack; S. H. Griffiths; R. Weck.
Associates: A. Evitts.

Honorary Member

At its June meeting, the Council elected to Honorary Membership of the Institute Mr. D. Llewellyn, F.I.M., in recognition of his distinguished contribution to the growth of welding, both by research and at the Ministry of Supply Welding Training Centre at Portobello, where for three years from 1942 to 1945 he lectured on welding metallurgy to a very large number of welding foremen and supervisors from industry. Mr. Llewellyn also played a leading rôle in the East of Scotland Branch of the Institute, and was its first chairman.

The President 1961–2

Mr. **H. West**, M.Sc., M.I.Mech.E., M.I.E.E., Managing Director of A.E.I. Ltd., took office as the new President at the Annual General Meeting of the Institute on 13th July.

Biographical details of Mr. West were published in the August 1960 issue of *BWJ* (p. 531).

New Vice-Presidents

Also at the Annual Meeting, Mr. C. **Humphrey Davy** and Mr. **L. Redshaw** took office as newly elected Vice-Presidents.

Mr. **L. Redshaw**, M.Eng., M.R.I.N.A. M.Inst.W., was born in Barrow-in-Furness, and was educated at the Barrow Grammar School. He commenced his apprenticeship in the Ship Drawing Office of Vickers Ltd. in 1927.

In 1931 he won an Open Scholarship in Naval Architecture and studied at Liverpool University, obtaining a First Class Honours Degree in Naval Architecture. He was awarded the 1851 Royal Commissioners Exhibition Post-Graduate Scholarship, and spent part of this period on welding research, being awarded his Masters Degree in 1936.

After joining the Management Staff of Vickers-Armstrongs in the same year, he was appointed Assistant to the Shipbuilding Manager, Barrow Yard, in 1945; and in 1950 he took over as Shipbuilding Manager, being appointed a Special Director in 1953.

On the formation of Vickers-Armstrongs (Shipbuilders) Ltd., in July 1955, he was appointed Shipbuilding General Manager of the Yards at Barrow and Newcastle, and in 1956 he was appointed to the Board of Directors of that Company, He is also a director on the Board of Vickers Research Ltd.

Mr. Redshaw is a member of the Executive Committee of the Shipbuilding Employers' Federation, a member of Council of the Royal Institution of Naval Architects, and also a member of the North East Coast Institution of Engineers and Shipbuilders. He was elected a Member of the Institute of Welding in 1945.

L. Redshaw

Staff

Assistant Technical Officer (Education)

Mr. J. R. Partridge has resigned the post of Assistant Technical Officer to take up an appointment with Freeman, Fox and Partners.

The Institute is seeking from among its members and others a successor to Mr. Partridge who would be qualified to assist the Technical Officer in the development of the Institute's educational work, both in the School of Welding Technology and over the whole field of co-operation with technical colleges, universities, and other educational bodies.

This is an appointment of great importance to the Institute at a time when its educational programme is rapidly expanding and a new standard is being set by the Post-Graduate Course in Welding Technology at Cranfield.

Members who are interested can obtain fuller particulars from the Secretary.

Librarian

Mr. J. H. Martin succeeded Dr. Sinclair as Librarian of the Institute on 10th July. Mr. Martin held various appointments with the Essex County Library from 1947 to 1959, and has been Assistant Technical Information Officer in the Central Laboratory Library of the de Havilland Aircraft Co. Ltd., at Edgware, since March 1959.

PUBLICATIONS

A copy of the following IIW publication is available in the Library of the Institute for borrowing or consultation by members:

IIS/IIW–80–61 (ex doc. SST–316–61) "*Nomenclature of welding processes*".

METAL SPRAYING DIVISION

At its meeting in July the Council of the Institute approved a constitution for a Metal Spraying and Plastic Coating Division of the Institute, to advance the aims and objects of the Institute in respect of metal spraying and plastic coating. It will seek to bring together interested members of the Institute so as to increase the body of technical knowledge on these subjects and to promote its dissemination through meetings, works visits, demonstrations, instruction courses, publications, and in general through all the means organised under the authority of the Council of the Institute.

The Division will be composed of members of the Institute in all classes, admitted to the Division by the Committee of the Division, who will, together with appropriate Honorary Officers, be elected by the Division members.

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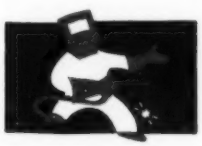

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This is of course a new form of organisation for the Institute, and it is modelled on the organisation provided for branches. It is the hope and expectation of the Council that the new Division will make such success in the achievement of its objects that other Divisions concerned with particular welding processes or with processes allied to welding will be called for before very long.

Further particulars of the Division will be circulated to members and others very soon, and it is hoped that the first meetings will be held during the 1961–2 winter session.

SCHOOL OF WELDING TECHNOLOGY

The provisional programme of courses from October 1961 to March 1962 is as follows:

D.1/4—Welded pressure vessels 2/6 Oct.
D.13/3—Residual stresses and stress relief 16/17 Oct.
D.12/3—Practical control of distortion 18/20 Oct.
D.17/1—Advanced course for Welding Engineers 13/17 Nov.
D.3/3—Design for welding in general engineering 4/8 Dec.
D.35—Design of welded pipe-work 29/30 Jan.
D.5/4—Non-destructive weld examination 12/16 Feb.
D.34—Welding metallurgy 26/28 Feb.
D.38—Hardfacing 15/16 Mar.
D.36—Interpretation of weld radiographs 2/6 Apr.
D.45—Advanced brazing technology 14/18 May
D.22/1—Welding of atomic energy plant 28/31 May

NEWS OF MEMBERS

Mr. **E. J. Bradley**, A.M.I.Mech.E., A.M.I.Struct.E., A.M.Inst.W., has been appointed Works Manager of E. Boydell & Co. Ltd. Manchester.

Dr. **F. Koenigsberger**, who was the first teacher of welding in a university institution in this country, has been appointed Professor of Machine Tool Engineering at the Manchester College of Science and Technology, University of Manchester.

Professor Koenigsberger, who joined the Institute in 1941, is a past Chairman of the Institute's Education Committee and of its Manchester Branch, and has been the U.K. delegate on Commission XV of the International Institute of Welding since its formation.

Professor **J. F. Baker**, Head of the Engineering Department, University of Cambridge, who has been a member of the Institute since 1935, and whose researches in plastic design of structures have contributed so pre-eminently to the advancement of welding science, was made a K.B. in the Birthday Honours. This honour gives great pleasure to Professor Baker's many friends in the Institute.

Mr. **F. A. Thomas** and Mr. **A. D. Marsh** recently celebrated the completion of 25 years' service with the Lincoln Electric Co. Ltd. They are the first holders of the Lincoln Long Service Club '25 year' badge, and have been presented with gold watches.

Mr. **V. F. L. Caers** is Director of a newly formed organisation, Welcon Ltd., architectural iron workers.

Obituary

The Council regrets to record the deaths of the following members:

Mr. **E. H. Skinner** (Tyneside Branch, Member 1941).

Mr. **C. S. Milne** (S. London Branch, Member 1928). An appreciation of Mr. Milne is given below.

Mr C. S. Milne

An appreciation by Mr. E. Seymour-Semper

Charles Stephen Milne came into the world in 1884 in an age, as he used to say, "when motor cars were non-existent" and he could remember people riding penny-farthing bicycles.

He served his apprenticeship in the old Taff Vale Railway in Cardiff, and when he completed it, in the early days of this century, fusion welding was just emerging as a novelty. In 1906 gas welding was first exhibited at the Engineering Exhibition by Thorn and Hoddle. At that time Mr. Milne joined Imperial Light Ltd. and designed an acetylene generator for welding, which was shown at the Engineering Exhibition in 1910. He was then so impressed with the possibilities of welding that he resigned from Imperial Light and commenced his own business in 1911. Inevitably he had many struggles before it became established, because he found that before he could sell welding equipment he had to sell the idea of welding, which at that time was looked upon with considerable scepticism. However, the exigencies of World War I gave Mr. Milne the opportunity to show what could be done by welding, and some of his early work in 1912 and onwards is illustrated in the Institute *Transactions* of June 1951.

The business of C. S. Milne & Co. is now widely known almost throughout the world, and many hundreds of Milne acetylene generators are in use. It is, however, for his personal qualities that Mr. Milne will be long remembered, for he had a very charming and attractive personality.

He joined the British Acetylene Association about 1912, and was President in 1919 and again in 1933. He did not, however, join our Institute until 1928, because there had been intense competition between gas and arc welding, and the view was held in some quarters that the Institute was pushing arc welding at the expense of gas welding. Mr. Milne often reminisced about these battles, and used to say that he joined the Institute so as to keep the electric arc welding people in order. He soon came into Institute committee work, and the Institute today owes much to devoted work pioneered by such as Mr. Milne.

In 1949, when Vice-Presidents were proposed in open Council, I had the privilege of proposing him for that office, and such was his popularity that he was nominated with the warm acclamation of all Council members present. His Presidency in the succeeding year was marked by two rather lively Annual Meetings, at which Mr. Milne by his charm and wit kept a small but verbose minority in good humour. His speeches at Branch functions combined common sense with a lively wit, and were always looked forward to.

He gave to the Institute, not only his time, but many gifts including the stained glass window with the Institute's coat of arms, which now hangs over the entrance door in the hall at Princes Gate. He was interested in the Institute's educational work, and the anonymous donor, who in 1957 gave a cheque for £50 to further this work, was Mr. Milne.

He took part in the formation of the International Institute of Welding and was the first British representative on the Gas Welding Commission, culminating in his holding a Vice-Presidency for three years.

Mr. Milne was very fond of telling, and listening to, a good story, and many will remember his skill in writing those charming little rhymes which he sometimes introduced into his speeches.

Again on the social side, whoever can forget the Milne parties held in a large London restaurant, when Mr. Milne invited his customers, competitors, and friends (but to him they were all friends) to a generous evening's entertainment.

He loved people, especially young people, and those who have been privileged to visit his home will recollect how his unfailing good humour combined with Mrs. Milne's graciousness to enrich the homely atmosphere. In his home he was affectionately called "Pop", but affection for him extended far beyond the boundaries of home life, and at International meetings in many European capitals I have heard delegates and their wives greet their old friend "Pop" with obvious sincerity. His happy philosophy for living was seen in his Presidential Address from which I quote – "To our younger members I would say when you join any organisation don't worry too much about what you are going to get out of it; your worry should be how much you can put into it." That is typical of Charles S. Milne, of whom it can be said with great truth – "He was an English gentleman".

CONTRIBUTORS TO THE JOURNAL

M. G. Nicholas, Ph.D., is a Senior Engineer in the General Telephone and Electronics Laboratories, New York. He was born at Bromsgrove in 1933 and attended various schools in Birmingham before entering the University there in 1951, where he studied in the Department of Industrial Metallurgy. He received a B.Sc. with 1st class honours in 1954, and on completing his National

Service obligations in the autumn of 1956, he returned to the Department to undertake research on the mechanism of bonding in pressure welding. As a result of work in this field, part of which is presented in the paper published in *BWJ*, he was awarded a Ph.D. in the summer of 1959.

Dr. Nicholas remained in the Department as a Research Fellow, continuing work along similar lines, until April 1960, when he left to take up his present position. As a Senior Engineer at the Laboratory he is currently concerned with studies of the initial stages of bonding compacts and the physical processes responsible for the long term reliability of certain types of electrical connections.

BRANCH NEWS

Liverpool

Design details

The meeting held at Byrom Street on 14th March was the occasion of a visit by Mr. H. B. Merriman, who presented his lecture '*Welding and the Draughtsman*' that has been so successful at other Branch meetings.

Mr. Merriman's lecture is an excellent example of practice put on to paper and it is strongly recommended not only to draughtsmen, but also to the welding engineers and ship fabricators, no matter to what part of the welding industry they belong. The experiences quoted are from work in the design of pressure vessels and there is a great deal of likeness between the requirements for these and parts of a ship's weldments and numerous applications to marine boiler and engine installations.

Sections of pressure vessel work associated with the chemical and nuclear energy engineering use a good deal of stainless steel of one quality or another, so much of the discussion following the lecture in Liverpool circled around rods and techniques for these steels. Electrode selection for welding 18/8 to mild steel was requested and 18/8/3 was recommended, no stress relief being necessary. Joint preparation was a straightforward V or J type. A 35/20 Inco rod is sometimes used without preheat or postheat. The stabilising elements can be stacked to work against one, the lecturer explained; so it is most essential to put in the correct amount of ferrite to produce the right ductility in the weld joint. The Americans prefer a rod with a 25/20 composition.

Concerning the use of particular alloys in electrodes another questioner asked if the necessary results could not be controlled by giving special attention to the length deposited per run of electrode at an optimum amount of current. This appeared to be quite correct in principle, as a series of short runs would be advantageous in helping to reduce the amount of pick-up. In addition, carbon migration occurs only over small limited areas.

Asked what advice should be given to draughtsmen employed in industries which do not specialise in welding so much, Mr. Merriman had noted that some study all about riveted joints and their efficiencies etc., but do little or nothing about training for welding. It is a good thing to get a staff to *do* actual welding when interviewed for a job, for it has been observed that very, very few draughtsmen have actually done welding. British Industry generally is really very backward in welding and it is both a sobering and a frightening thought to see how thoroughly welding has been taken up in other countries.

In Portugal, where the lecturer had spent 18 months, he had seen some of the best pipe welded fabrications in the world, carried out by enthusiastic men using the best equipment obtainable. The German pressure vessel work and rail car fabrication are most impressive, and in Italy the competition is enormous. A craft welder in Portugal gains social status because of his special abilities in joining metals together.

A member stated that engineering post-graduates were coming from the university to the technical college in order to learn and practise welding. This was done first in Colchester and now in Liverpool. At Billingham engineers take a fortnight's welding course in the laboratory. There is indeed a void in most engineers' welding experiences but some firms are beginning to send their men in batches to the colleges to obtain practical welding training.

Finally, there arose a question concerning the use of 18/8 pads on an 18/8 shell, the pads having to take carbon steel supports. It is done this way to avoid weld contamination but it was suggested that the same could be achieved by depositing runs of austenitic electrodes to make the mild steel connection direct to the stainless shell.

Mr. Merriman agreed the direct connection could be made for 10 s.w.g. shell and thicker, but for thinner plating recommended the pads.

H.R.C.

Wolverhampton

Annual Dinner and Ladies' Night

On Friday, 14th April, 1961, the Branch held its 16th Annual Dinner and Ladies' Night at the Wulfrun Hall. Mr. E. J. Mitchell took the chair and the principal guests of the evening were the Mayor of Wolverhampton, Alderman H. Mash, Mr. R. G. Braithwaite, Past-President of the Institute, who very kindly stepped into the breach at the last moment to respond to the toast of "The Institute of Welding", Mr. Peter Shaw, Sales Manager of the Electric Welding Division of B.O.C., who gave a toast to the "Wolverhampton Branch". About 334 members and guests sat down to dinner and afterwards danced to the music of Stan Fielding and his Band.

EDUCATION

Advanced Course on Welding Technology

Applications are still being received by the College of Aeronautics, Cranfield, for the Post-Graduate Course on Welding Technology, which is to open on 9th October next.

The prospectus for the Course was published in the May issue of *BWJ*, and copies are still obtainable from the College or the Institute.

The Course will be held in the Department of Materials Engineering in charge of Professor A. J. Kennedy, and the College has announced the appointment of Dr. R. L. Apps as lecturer and Mr. L. M. Gourd as instructor.

Pressure vessel design

Much recent research on pressure vessel design has shown the need for a more fundamental approach. With this object in view the Manchester College of Science and Technology is providing a short course of lectures on "Pressure Vessel Design" to be held in the College from Tuesday 12th to Friday 15th September, 1961. The Course will survey modern methods of analysis, recent knowledge of material properties, and their application to pressure vessel design problems. The

use of reinforced concrete vessels is also becoming of importance and the course will include lectures on this subject.

The course will be valuable to all concerned in the design, application and use of pressure vessels in all industries. It will be easily followed by graduates or those with a Higher National Certificate or Diploma in engineering, physics or chemistry.

The lectures will include the following:

"*Analysis of cylindrical shells. Edge solutions and the 'beam on elastic foundation' problem*" by Dr. S. S. Gill
"*Membrane and edge solutions for shells which are surfaces of revolution*" by Dr. S. S. Gill
"*The use of membrane and edge solutions as applied to the junction of shells of different geometry, pressure vessels support problems*" by R. Kitching
"*Analysis of local loading problems as applied to shell openings and discrete supports*" by R. Kitching
"*Thermal stresses in pressure vessels*" by Professor W. Johnson
"*Stress concentrations at openings in cylindrical and spherical vessels*" by Dr. R. T. Rose
"*Methods of solution for shells forming surfaces of revolution with particular reference to corrugated ducts*" by Dr. P. J. Palmer
"*Design Codes*" by R. F. Bishop
"*Choice of pressure vessel material*" by J. F. Lancaster
"*Creep, stress rupture and stress relaxation of pressure vessel materials*" by R. W. Nichols
"*Mechanical and thermal low endurance fatigue. General considerations of load cycling and mechanical and thermal strain cycling up to 10^4 cycles*" by Dr. P. P. Benham
"*The brittle fracture problem as it concerns pressure vessels*" by Dr. L. E. Benson
"*Corrosion problems associated with pressure vessel materials*" by Dr. I. A. Menzies
"*Engineering design aspects of concrete pressure vessels*" by I. W. Hannah
"*Materials problems related to prestressed concrete vessels*" by C. R. Lee
"*Special problems in the analysis and design of pre-stressed concrete pressure vessels*" by Professor Dr.-Ing Kurt Billig

Applications to attend the course should be made by 31st August, 1961. Residential accommodation is limited and in the event of applications exceeding the accommodation available places will be allocated in the order in which they have been received.

The fee for the course will be £13 10*s*. inclusive of coffee, lunch and afternoon tea at the College.

All enquiries concerning the course should be addressed to the Registrar, The Manchester College of Science and Technology, Manchester 1.

Revised schemes for plumbers

The City and Guilds of London Institute announce that, to make it possible for the National Joint Council for the Plumbing Industry to award their Certificates of Competency in Welding to successful candidates, modifications have been made to the post-Final scheme 90—Welding in Relation to Plumbers' Work.

Candidates must now pass a 2½-hour written paper with some 'short-answer' questions, and they must also pass each test in two practical examinations. But there will be no specimen work requirement. The certificates issued by the National Joint Council are, initially, for both sections, *i.e.* mild steel pipelines and bronze welding but, under their regulations, annual renewal depends on continued practice in the type of welding concerned.

Radiography courses

Kodak Ltd. have issued a booklet which describes the courses held in their School of Industrial and Engineering Radiography. These include Lloyd's approved course in casting and weld radiography (4 weeks); surveyors' and engineers' course (2 weeks); and a course in gamma radiography.

CONFERENCES

Inspection and Testing

A National Conference to discuss the function of management in relation to inspection, the economics of inspection and non-destructive testing, and the recruitment, education, and training of inspection staffs, is being organised by the Institution of Engineering Inspection and the Society of Non-Destructive Examination.

The Conference will be held at Oxford in September 1961, and residential accommodation will be available at Queen's College and New College from 5th to 8th September. The cost, including Conference fee, accommodation and all meals, will be £9 10*s*.

Further information can be obtained from the Oxford Conference Secretariat, The Institution of Engineering Inspection, 616 Grand Buildings, Trafalgar Square, London W.C.2.

Czech Welding Congress

The Eleventh International Welding Congress is to be held at Smolenice Castle, near Bratislava, Czechoslovakia, from 12th to 14th September, 1961. It is being organised by the Slovak Academy of Sciences, the Welding Research Institute, and the Czechoslovak Scientific-Technical Society.

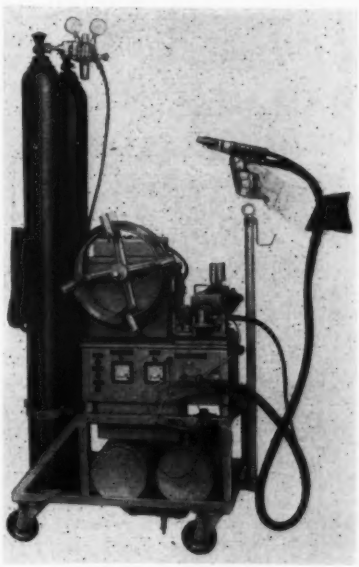
The main theme of the Congress will be the 'Theory of Welding Processes' and topics will include welding metallurgy, physics of welding processes, and structural processes in welding.

During the Congress visits will be paid to the Welding Research Institute in Bratislava, and to the International Brno Trade Fair.

NEWS FROM INDUSTRY

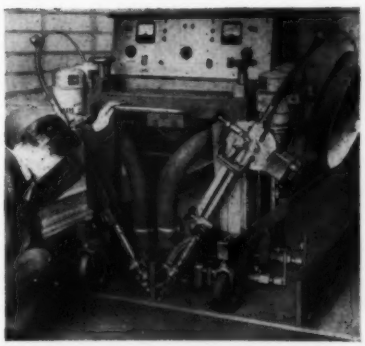
Engineering, Marine, Welding and Nuclear Energy Exhibition 1961

The general impression of welding equipment gained from a visit to the Exhibition was one of steady development and refinement rather than of outstanding progress. A prominent

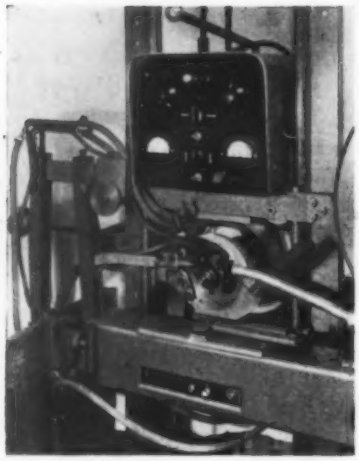


Lincoln-Cloos type CA3 semi-automatic CO_2 unit

feature was the variety of CO_2 arc welding plant, most of which has been made available in this country since the last Exhibition in 1959. This equipment is of two types, namely straight CO_2 and CO_2 plus flux. Of particular interest in the latter category is the equipment employing a magnetic flux,



Murex Muramatic automatic twin-fillet welder



Rockweld Vertomat carriage and controls

carried to the welding head in the CO_2 supply, which is attracted to the electrode wire by the magnetic field which surrounds it. Other equipments use cored or covered electrodes.

A special adaptation of CO_2 arc welding equipment is the Rockweld Vertomat, similar in operation to the electro-slag machines, but in which the welding operation is shielded by CO_2 gas.

The electro-slag process did not feature so prominently in this Exhibition as it did in 1959, possibly because of the limited field of application which it has so far found in this country.

Highly developed positioning equipment was much in evidence, this reflecting the importance attached by industry to automatic welding and high productivity in manual welding.

A number of companies were exhibiting special machines for profiling pipes for branch connections, a reflection of the importance of pipework in modern industrial plant.

In the field of non-destructive testing, two developments were significant. One was the introduction of xeroradiography, a process as yet little applied to the examination of welding, but one which shows great promise. The other was the inclusion of an attenuator in ultrasonic flaw detection equipment for the estimation of defect size.

A number of new welding processes have yet to be launched on the industrial scene in this country, for example plasma-jet and friction welding. We may hope to hear more of them in the future.

J.L.S.

Low-temperature welding and brazing

Earlier in the year, a new company, Welding Improvements Ltd., of Northampton, was formed to market a new range of low heat input metal joining alloys. These include metal-arc electrodes and gas welding and brazing alloys suitable for a wide range of materials.

The electrodes, rods, and fluxes are being sold under the trade name of 'Fontargen'.

Fe + Zn

This is the simple title of the Bulletin of the European General Galvanizers Association, the first issue of which has just been released. The Bulletin is intended for users of galvanised steel, and in each issue the more important fields of application will be reviewed. Copies can be obtained from the Zinc Development Association.

Universal Beams

Colvilles Ltd. are expecting that the new universal mill built by the Lanarkshire Steel Co. Ltd. will be producing a range of broad flange, or universal, beams towards the end of the year. The maximum size will be 24 in. × 9 in.

Ultrasonic welding equipment

The Derritson Electronics Group and Darlington Chemicals Ltd. have announced their association in forming a new company, Pulsonic Ltd., which will specialise in ultrasonic welding equipment.

It is expected that standardised models will be available by the end of the year. In the meantime, the pooling of earlier research by both companies has enabled prototype equipment to be given extensive tests.

Oxy-cutter for new rolling mill

The new rolling mill at the South Works of the South Durham Steel and Iron Co. Ltd., has been equipped with a BOC 'Oxyplane' machine, with a track length of almost 100 ft.

The machine, which prepares the longitudinal and transverse edges of plates in one operation, using propane as the fuel gas, can deal with plates up to 97½ ft. long, 12½ ft. wide, and between ⅜ in. and 4 in. thick. The cutting heads can be arranged to give a square edge or single or double-bevel profiles.

PLANT AND EQUIPMENT

Sheet shears

A novel form of shear is being produced by Ferrous Transformers Ltd. for cutting and shaping sheet metal up to ¼ in. thickness (ferrous) or $\frac{3}{16}$ in. (non-ferrous).

The machine works on the principle of removing a narrow strip of metal from the waste side of the cut, so avoiding distortion and buckling. This feature also allows long sheets to be fed and cut freely.

Microtex X-ray film

Kodak Ltd. have introduced a new range of X-ray films, 'Microtex', with extremely fine grain and high contrast. They are stated to be suitable for detecting fine porosity and lack of fusion in welds.

Mild steel electrodes

The well-known Diadem 'Ruby' range of electrodes produced by Cooper and Turner Ltd., has recently been improved to give better slag detachability and absence of objectionable fumes. The electrodes are classified as E.217 (BS. 1719) and have full Ministry of Transport, Lloyd's and other official approvals.

Scleroscope hardness testers

Two hardness measuring instruments, using the Shore Hardness Scale, are being marketed in Britain and the Commonwealth (except Australia) by Griffin and George (Sales) Ltd. on behalf of the Stove Instrument and Manufacturing Co. of New York.

One model, the C.2, is a direct reading instrument, suitable for 'free-hand' testing of thin metal sheets. The other, Model D, has a dial and pointer for reading the hardness value, which can also be determined on Brinell and Rockwell C scales, and is used in the clamped position on the work piece.

CORRECTION

Aluminium stud welding

In our note on the argon-shrouded stud welding process (*BWJ*, May 1961, p. 288) it could be inferred that the maximum size stud is limited to $\frac{7}{16}$ in. dia. We are informed, however, that by the combined use of an argon shroud and preheater unit completely reliable welds can be formed with studs up to ½ in. dia.

STUB ENDS

● Mr. G. W. Lacey, C.B.E., has been elected President of the Aluminium Development Association. Mr. Lacey is Asst. Managing Director (Overseas) of the British Aluminium Co. Ltd.

● Mr. A. F. Chouinard, Director of Research and Development of the National Cylinder Gas Company, has been elected President of the American Welding Society.

● Viscount Simon, C.M.G., has succeeded Viscount Runciman of Doxford, O.B.E., as President of the Royal Institution of Naval Architects.

● The Institution of Structural Engineers has elected Mr. F. R. Bullen, B.Sc.(Eng.), M.I.C.E., President for the session 1961–2.

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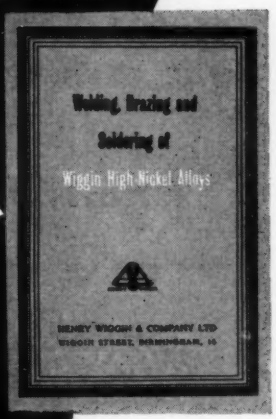

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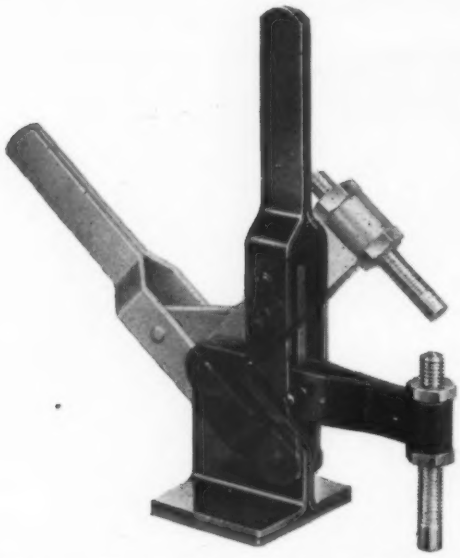

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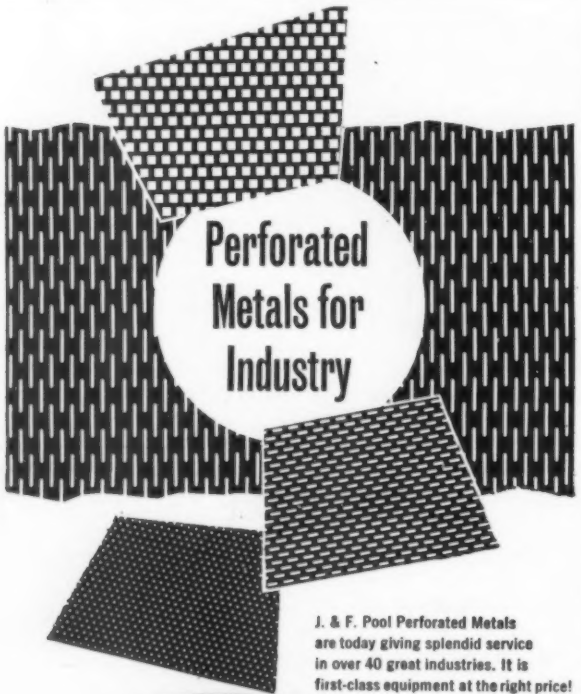

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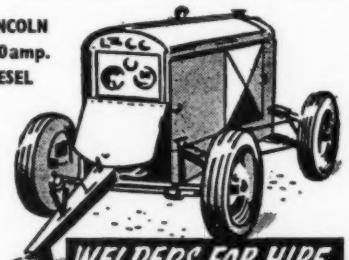

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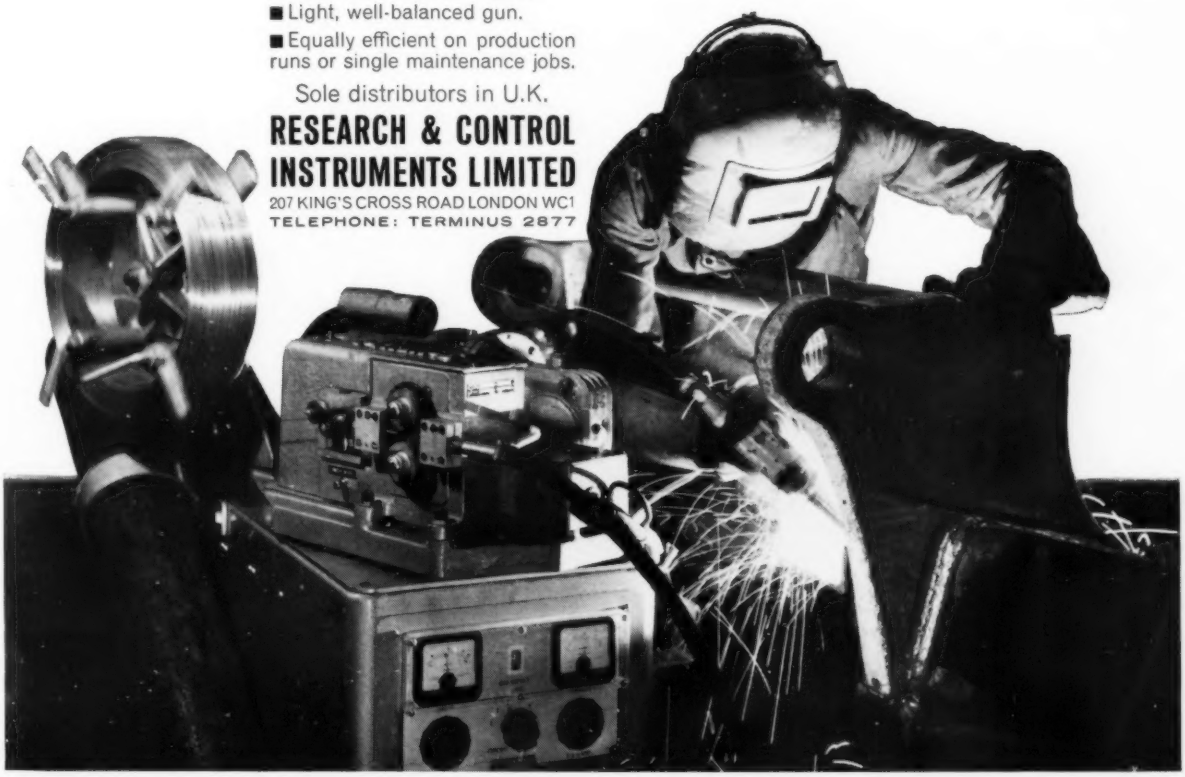

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